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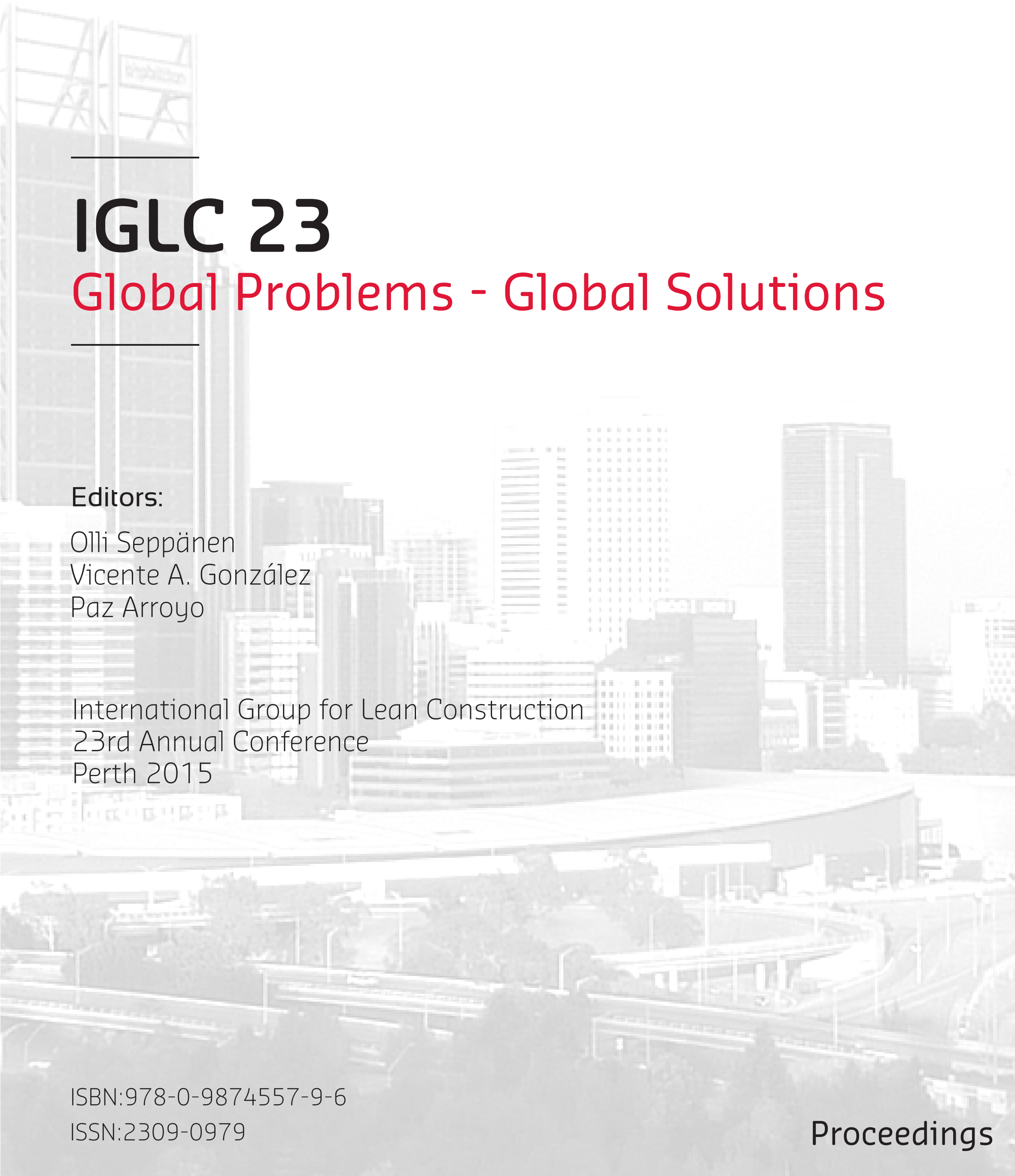

IGLC 23

Global Problems - Global Solutions

Editors:

Olli Seppänen
Vicente A. González
Paz Arroyo

International Group for Lean Construction
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23RD ANNUAL CONFERENCE
OF THE
INTERNATIONAL GROUP
FOR
LEAN CONSTRUCTION

GLOBAL KNOWLEDGE – GLOBAL SOLUTIONS

Edited by
Olli Seppänen
Vicente A. González
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Perth
Australia
July 29-31 2015

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INTRODUCTION

The International Group for Lean Construction (IGLC) is a network of professionals and researchers in architecture, engineering and construction (AEC) who feel that AEC has to be radically renewed in order to respond to the challenges head. The goal is to increase stakeholder value, decrease the huge amount of waste currently present in design and construction activities and to generally improve the performance of the construction industry. New principles and methods developed by the group are based on lean production theory adapted to the construction sector. The IGLC webpage (http://www.iglc.net) presents more information as papers from all previous conferences.

The venue of the conference has been alternating between South America, North America, Europe and Asia/Oceania. The 23rd IGLC Conference is the third IGLC to be held in Australia. This year, IGLC is organized together with various other related events. The combined name of all the events is Construct15. Construct15 will bring in a large number of industry practitioners and academics who will also be exposed to the IGLC conference.

85 papers from 17 countries are published in these proceedings, a lower volume than in previous conferences but a great result considering that Perth is a long distance from most of the authors. The papers are organized in 14 tracks which are the same as in previous years although a few tracks (3) did not get any accepted submissions. Table 1 shows the number of abstracts and papers submitted and papers accepted for each track. Production Planning and Control (21 papers) continues to be the largest track, followed by People, Culture and Change (10 papers). BIM and Lean had the same number of papers as last year (7 papers) which may be a sign of its increasing importance to the lean community.

IGLC's are meant for both academics and practitioners and we continue the tradition of including industry papers which may not have the traditional structure of research papers or use scientific methods to support conclusions. Industry papers may present interesting case studies and can be sources of new knowledge, ideas and discussion in the conference. In IGLC 23, the number of industry papers was 5 which is down from IGLC 22 (20 industry papers). This decrease may be partly due to industry collaborating more with academics with practitioner and academic authors in one paper. Industry papers are included within their track in presentation sequence but have a note "Industry Paper" in their header. In this year's proceedings we will also publish papers presented in the poster session (13 papers). These papers are intended as additional information for interesting posters. However, the poster papers were selected from borderline papers so they usually represent premature research with future potential in the lean construction space.

Table 1: Submissions and accepted papers by track

Track	Submitted papers	Accepted			
		As Research	As Industry	As A3	Total
Production Planning and Control	31	20	1	3	24
Design Management	11	7		1	8
People, Culture and Change	13	9	1		10
BIM and Lean	9	6	1	1	8
Integrated Project Delivery	5	4	1		5
Contract and Cost Management	3	3			3
Theory	12	7		1	8
Supply Chain Management	2	0			0
Teaching Lean Construction	5	4			4
Value	5	0		3	3
Sustainability, Green and Lean	7	1	1	2	4
Industrialization and prefabrication	2	2			2
Safety and Lean	3	0			0
Waste in Construction	10	4		2	6
Total	118	67	5	13	85

Table 2 shows papers accepted by country, using the first author's location. 19 papers had authors from more than one country. This shows that international collaboration is increasing since last year's proceedings had just 16 out of 125 papers with authors from more than one country and this year we have 19 out of 85 papers!

Table 2: Number of papers accepted based on the country of first author's institution

Country of the first author's institution	Published papers
United States	18
Norway	11
Brazil	9
United Kingdom	8
Germany	7
Chile	6
Finland	5
New Zealand	4
Australia	3
China	3
Lebanon	3
Colombia	2
Malaysia	2
Ireland	1
Israel	1
Luxembourg	1
Sweden	1
Total	85

All papers in the proceedings have undergone a double blind review process. Most of the accepted papers made significant changes in order to answer reviewer comments and were greatly improved. We want to thank all 81 reviewers for improving the quality of papers.

We would like to thank the track chairs for organizing their tracks. The track chairs are: Farook Hamzeh (Production Planning and Control), Rafael Sacks (BIM and Lean), Carlos Formoso (Waste in Construction), Christine Pasquire (Teaching Lean Construction), Lauri Koskela (Theory), Luis Fernando Alarcón Cardenas (People, Culture and Change) and Patricia Tzortzopoulos (Design Management). We also want to thank our editorial assistants Mani Poshdar, Camila Fuenzalida, Saleh Alazmi, Md (Ronnie) Rahman, Sheila Belayutham, Hamed Golzarpoor, Rehan Masood and Camila Fuenzalida, who helped prepare the proceedings for printing and also edited a lot of papers to comply with Anglia Ruskin Harvard reference guidelines.

Espoo, Auckland and Santiago, June 25, 2015

Olli Seppänen, Vicente A. González, Paz Arroyo
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COMPARISON BETWEEN LOCATION BASED MANAGEMENT AND TAKT TIME PLANNING

Adam G. Frandson[1], Olli Seppänen[2], and Iris D. Tommelein[3]

ABSTRACT

Construction planning methods may or may not explicitly model space as a resource. This paper compares two methods that do. The first method is used in the Location Based Management System (LBMS). The second method is Takt Time Planning (TTP). Both are iterative design methods for planning and controlling construction work, both focus on creating a balanced production schedule with a predictable timing of work while also preventing spatial interference between trades, but they differ in how they achieve these goals. The contribution of this paper is to (1) highlight the similarities and differences between these two methods and (2) describe a proposal for future exploratory research to evaluate the systems using common metrics.

KEYWORDS

Location Based Management System (LBMS), Line of Balance (LOB), Takt Time Planning (TTP), buffers, resource continuity.

INTRODUCTION

Space is a resource to consider when planning construction projects (for brevity, we use the term "planning" to include scheduling); despite being omni-present it is often overlooked. Space is important especially in construction because, unlike manufacturing where the work moves to the people, on a construction site the people move to the work (Ballard and Howell, 1998).

Two planning methods that take space into account are compared in this paper: (1) the Location Based Management System (LBMS) and (2) Takt Time Planning (TTP). This paper follows the comparison of planning methods presented by Seppänen (2014) that was based on his deep understanding of LBMS but his narrow interpretation of TTP.

First, this paper presents background on location based planning in construction. Second, it will describe the two methods of planning. Third, it discusses the

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similarities and differences between these two methods. Finally, the paper describes a proposal for future research to evaluate the systems using common metrics.

HISTORY OF LOCATION BASED METHODS

Location based methods for planning and control have a long history. In the late 1920s, builders of the Empire State Building used location based quantities and a kind of flowline diagram to plan and control the work. Their goal was to establish a production line of standard parts (Willis and Friedman, 1998). In the 1940s, the Goodyear Company developed a systematic method for location based planning called Line of Balance (LOB). LOB was deployed for industrial programming by the US Navy in WWII (Lumsden, 1968) but also applied to repetitive construction. LOB was a graphical technique that relied on repetition, so it was implemented in highly repetitive building projects, such as housing development programs (ibid.), road construction, etc. Suhail and Neale (1993), Arditi, Tokdemir and Suh (2002), and others continued modelling location based planning using LOB lines consisting of Critical Path Method (CPM) networks with tasks that are repeated between locations.

The flowline method (a term coined by Mohr in 1979) was based on work by Selinger (1973, 1980) and his supervisor Peer (1974). A difference is that LOB diagrams do not explicitly show the movements of crews because tasks are presented as dual lines, whereas flowlines represent each task as a single line. Flowline thus requires more detailed planning because it is necessary to be explicit about resources use. Mohr (1979) discussed the detrimental impact of work breaks on production, and the risk of return delay when crews leave the site.

The next developments attempted to integrate CPM and location based models in such a way that they could be computerized and allow for non-repetitive construction. Russell and Wong (1993) developed a method termed *representing construction* that allowed for multiple types of CPM logic within a location based model, free location sequencing and non-repetitive tasks in addition to other features. They allowed for work to be continuous or discontinuous, part of workable backlog or cyclic. Logic could be typical or non-typical. Harris and Ioannou (1998) reconciled the work on location based planning done by others and highlighted that one cannot minimize the duration of a schedule while maintaining continuity of resource use at all times.

Much work related to methods of location based planning has been done by Kiiras (1989) and Kankainen (e.g., Kankainen and Sandvik, 1993). That work was based on planning to manage schedule risk through continuous flow of work and control aimed at reducing interference. Over 30 action research case studies were documented in masters’ theses.

LOCATION BASED MANAGEMENT SYSTEM (LBMS)

LBMS PLANNING METHOD

Kenley and Seppänen (2010) developed their Location Based Management System (LBMS) by building on this previous work. Their innovations on the planning side include (1) layered logic and (2) calculations adapted from CPM that make it possible to optimize the schedule while allowing the enforcement of continuous work. Flowline remains the means to visualize schedules.

As starting data, LBMS requires the Location Breakdown Structure (LBS), tasks, quantities for each location and task, labor consumption rate for each quantity item, workhours and workdays (calendar) for each task, optimum crew composition for each task and logic between tasks. Tasks can include several locations of similar, repetitive work in sequence of production. By default the schedule calculation is based on achieving continuous flow by delaying the start date of early locations (Kenley and Seppänen, 2010, pp.123-162).

Kenley and Seppänen (2010, pp.204-213) present guidelines for defining the LBSs of a project. LBS is a critical planning decision because it impacts the quantity take-off, the number of logic relationships required to schedule a project, as well as variation of quantities between locations. LBMS calls for physical, clearly defined locations so that there is no ambiguity about location boundaries. Kenley and Seppänen (2010) propose that the same LBS should apply to all or most trades, and certainly to all trades in the same phase. For interior work, they recommend dividing locations by type of space (e.g., office vs. corridor), because different trades' working different functional spaces with different logic and different quantities. These spaces can be grouped by location and then type (e.g., North patient rooms vs. North operation rooms). Finally, they propose eliminating implicit buffers by planning small locations and using finish-to-start relationships. Implicit buffers arise when locations are large enough for multiple trades and finish-to-start relationships are used because it would be possible to start the successor earlier without causing interference. Seppänen, Ballard and Pesonen (2010) proposed that LBS be defined in a collaborative process involving trades in Last Planner® phase planning meetings.

Tasks are defined based on work (1) that can be completed by one trade in a location before moving on to the next location, and (2) that has the same external dependencies to other tasks (Kenley and Seppänen, 2010, p.216). Tasks and dependencies can be planned collaboratively in phase planning meetings. Typically, logic will be defined separately for each space type (e.g., corridors, office rooms, operation rooms, etc.) because the required logic may vary (ibid, p.219). In practice, this requires a different phase plan for each space type (but not for different locations including several spaces with the same type).

Seppänen, Ballard and Pesonen (2010) recommend that between two phase planning meetings trades collect quantity data and labor consumption rates. Trades estimate quantities for each identified task in each location and labor consumption (manhours/unit) for each quantity line item. A task can contain multiple quantity line items if there are different types of work performed by the same crew in the same location (e.g., large vs. small diameter ductwork). The selected labor consumption should be the optimal rate for production of the work for optimal crew (the natural rhythm as defined by Arditi, Tokdemir and Suh, 2002). This rate assumes that all the prerequisites of working will be available and workers will be able to work continuously without interference from others (Kenley and Seppänen, 2010, p.218). The goal of LBMS control mechanisms is to ensure that these optimal conditions are achieved for as many trades as possible, prioritizing tasks with high manhour content.

Optimization is done collaboratively with trades in the second phase planning meeting. The starting point of the meeting is a location based plan with one optimal crew for each task. This will result in a plan with tasks, some progressing at a gentle slope and others with a steep slope in a flowline diagram. In the meeting, workflow is optimized by starting with trades that have the gentlest slopes, so-called bottleneck trades (Seppänen, Ballard and Pesonen, 2010). The available optimization tools in order of desirability are (1) changing slopes by changing the number of crews or scope, (2) changing location sequence, (3) changing soft logic links, (4) splitting tasks (planned breaks) or making tasks discontinuous .The goal is to find a common slope for each phase (Kenley and Seppänen, 2010, pp. 221-230).

Finally, meeting participants analyse schedule risks (the likelihood of a delay occurring) and add time buffers so control actions can be taken if needed. The goal is to find a schedule with minimum cost that achieves the duration target and has an acceptable risk level. They may analyse the risk level through Monte Carlo simulation or qualitatively based on decisions taken to achieve the required slope. Risk is minimized first by trying to minimize variability. To account for any remaining variability, time buffers are added between the tasks to protect hand-offs. Their size depends on variability of the preceding task, the dependability of the trade, and the total float of the task (Kenley and Seppänen, 2010, pp. 233-239). Simulation can be used to inform buffer sizes. In terms of social process, Seppänen, Ballard and Pesonen (2010) propose that buffer sizes are discussed in the optimization meeting.

LBMS Control Method

The control method of the LBMS includes monitoring progress, calculating performance metrics, and forecasting future production based on actual production rates. Alarms are calculated when there is a risk of interference between trades (Seppänen, 2009). The forecast is adjusted to prevent production problems by planning control actions (Kenley and Seppänen, 2010, p.254). The analysis of alarms can be done by a dedicated production engineer who identifies any deviations, prepares material for team review, and facilitates a control action planning session with trades to get commitments to implement control actions (Seppänen, Evinger and Mouflard, 2014). The development of the forecasting method and empirical research on its effectiveness in addressing production problems has been researched by Seppänen (2009) and Seppänen, Evinger and Mouflard (2014). It should be noted that this system is based on having time to react with control actions before interference happens. This requires buffers in the location based plan.

LBMS control includes tracking of actual production rates and labor consumption at least weekly, but preferably daily for any tasks affected by committed control actions. Progress data is self-reported by trades and validated through site walks by the production engineer and superintendents (Seppänen, Evinger and Mouflard, 2014). The root causes for any deviations are analysed. Main deviation types are start-up delays, production rate deviation, splitting of work to multiple locations, out-of-sequence work and interrupted work (Kenley and Seppänen, 2010, pp.346-348). The impact of deviations is analysed by the production engineer using the schedule forecasts and alarms and validated with the superintendent(s). Finally, the production engineer initiates a collaborative control action process involving all affected trades to get back on track (Seppänen, Evinger and Mouflard, 2014). Possible actions include changing the production rate, changing the work content of the task, breaking the flow of work, changing the location sequence and overlapping production in multiple locations (Seppänen and Kankainen, 2004). Additionally resources can be assigned to work on workable backlog tasks if they would otherwise need to leave the site (Seppänen, 2014).

If there is insufficient time to react with control actions or control actions are not taken, an alarm can turn into an actual production problem. Production problems can be (1) start-up delays (a trade is unable to mobilize when committed), (2) discontinuities (a trade demobilizes), or (3) slowdowns (a trade's production rate decreases due to interference) (Seppänen, 2009). If (1), the forecasts are used to pull the trade on site when locations are available. If (2), the forecasts are used to find out a suitable return date. If (3), one of the trades will get to own the location and the other(s) must work on workable backlog or demobilize. All these decisions are made collaboratively with the trades based on the production engineer's input.

TAKT TIME PLANNING (TTP)

TAKT TIME PLANNING METHOD

The use of Takt time to plan construction work is rooted in the use of Takt time in (lean) manufacturing to set production rates that match the demand rate (e.g., Hopp and Spearman, 2008). Takt time is defined as: "the unit of time within which a product must be produced (supply rate) in order to match the rate at which that product is needed (demand rate)" (Frandson, Berghede and Tommelein, 2013).

Frandson and Tommelein (2014)—knowledgeable in CPM, LOB, and numerous space scheduling methods—developed the TTP method described in this paper and tested it on a pilot project; they have follow-on research underway. They see TTP as a method for work structuring (Ballard, 1999; Tsao et al., 2004) in order to design the production system for continuous flow. The objective is to produce a production plan (a plan used to steer and control construction work on- and off-site) that provides a balanced work flow for a certain scope of work in the time allotted. That scope typically spans a construction phase (e.g., overhead MEP installation, in-wall rough installation, interior finishes), that is, a period of time during which a number of trades have to perform interrelated work. "Balanced" refers to the desire to create a stable pace of work (matching the demand rate) for each trade, with each trade proceeding through a sequence of zones (not necessarily the same sequence or the same zones for all trades). This is similar to the "week beat" scheduling described by Court (2009). As is the case for locations in LBMS zones are "physical, clearly defined locations so that there is no ambiguity about location boundaries" and they may vary from one another. Zones, pace, and sequence are all system parameters that get determined through the iterative process called production system design.

A key characteristic of TTP is that each trade must complete their work in each assigned zone within a set amount of time, namely the Takt time. This design parameter, once set, is constant throughout the phase. In order to accomplish reliable work completion (the hand-off to the next trade), after driving out all variation that can be driven out yet recognizing that numerous uncertainties can hamper the execution of work, TTP uses capacity buffers. Trades must underload their production units, that is, assign them to work at, e.g., 70 or 80% of capacity.

One source of variation that is driven out through the design of zones is the variation in work density. "Work density" refers to the situation in an area on site based on (1) the amount of work required by one trade in a particular area, (2) the trade's crew sizing and capabilities, and (3) the trade's means and methods (when prefabricating off site, the work density decreases). As such, some areas have a higher work density than others (e.g., compare electrical work in a lobby compared to an operating room). Different trades will have different work densities as well. Thus, through data collection and design of the zones this work density variation from zone-to-zone and trade-to-trade can be reduced.

PROCESS OF TAKT TIME PLANNING

Frandson, Berghede and Tommelein (2013) described TTP as a six step process consisting of (1) data gathering, (2) zone and Takt time definition, (3) trade sequence identification, (4) determination of individual trade duration(s), (5) workflow balancing, and (6) production schedule finalization. The first five steps occur iteratively, similar to the 'rough to fine' production system design described in Ballard and Tommelein's (1999) paper on continuous flow.

Data Gathering: Developing a TTP requires collecting production data from each trade individually and the team as a whole well in advance of construction. A master schedule may have been established, but before any production planning is done, data gathering begins with a production team meeting, consisting of trades involved in the work and the general contractor (GC), to discuss the product of TTP. The team must set their overall production target (e.g., "a chosen Takt time, with a consistent trade sequence through out every zone and balanced work zones"). The target may be specific and based on previous experience with similar work, or more general if the work and production team are new to using Takt time. It must also reflect the time the team will have to complete the work and milestones in-between (e.g., specified in the contract including the master schedule).

The data to gather in conversation with the trades is specific to them, their work, and the project context. How do they want to move through this project's space? What alternatives are available? What are the material and manpower constraints, or work method alternatives? What work needs to be performed before they start work? What is the sequence of work internally (e.g., electricians want to set trapezes, run conduit, and then pull wire)? Can the sequence be split, or can the work be performed in a later phase (e.g., does the electrician have to pull wire immediately after the conduit is run)? Trades may color up plans in order to show their desired work flow, what can be completed and when and under which assumptions. In order to understand the set of options deemed feasible for a trade, though perhaps not optimal from their perspective, alternatives must be discussed with each trade so as to allow for a set-based approach in developing the phase schedule. Each trade's set of options can then be tested against the sets of options available to other trades, so as to develop a combined plan that is better for the project as a whole than could have been obtained had each trade individually offered only their most-preferred option, or had the GC pushed a schedule on the trades to comply with. A GC schedule embodies too many assumptions and constrains the trades' abilities to do what they do best. Better plans can be developed when the team is incentivized to address the "Who pays and who gains?" question with overall project optimization in mind.

The trade representative in the conversation must be able to provide this level of detail, e.g., the foreman able to commit to doing the work. The benefit to planning early with these details is that people develop deep understanding of both their production capabilities and the resulting plan from the collected information.

Zone and Takt Time Definition: Zone and Takt time definition relate to one another because the duration required to complete a task is dependent upon where and what needs to be built. Zones are defined by means of an improvement process, starting from zones, e.g., (1) already established in previous work phase. (2) created using the data gathered in a holistic manner (i.e., all the trades are considered when creating the zones). (3) designed to best satisfy (and then improve upon) the work of one trade because it is evident from data that their work will be the "bottleneck." This initial set of zones is the starting point for iteration.

Trade Sequence Identification: Given a set of zones, the trade sequences are obtained from each trade individually and then combined through phase planning in order to honor sequential dependencies while working through the construction documents or building information model with the team. When identifying the trade sequence—which doesn't need to be a line sequence (as in the Parade of Trades (Tommelein, Riley and Howell, 1999)), it's important to document the requirements each trade has in order to correctly hand off zones from one trade to the next.

Balancing the Plan: Balancing the plan occurs in a rough-to-fine fashion. From the proposed zones it is now possible to refine the task durations for each trade. Typically trade task durations will vary through the zones. Once the variation is known, the production team can begin to balance the production system.

The production team has several methods to balance the work flow and design the production system. We list these methods next but do not mean to imply any order in which to apply them. The team can iterate upon the zones. If the zones are consistently uneven across the trades, the team can redesign them. Ideally, if it is early enough the actual design of the project could be changed to improve production. Zones may be unbalanced due to the nature of what is being built (e.g., an operating room contains more work of certain kinds than a standard patient room). As such, some trades may have to leave out certain work and perform it "off Takt." The team can also revisit the work methods, trade scope (providing the contract structure enables money to flow across boundaries), and restructure the trade sequence in order to balance the work. Perhaps a trade can individually, or jointly with other trades, prefabricate more work, thus reducing their field installation times so they can meet a lower Takt time. The trade sequence could also change by splitting the trade work into multiple tasks (e.g., split electrical conduit installation from pulling wire) and thereby enable a faster Takt time. The overall schedule then shortens because a reduction in Takt time scales across the number of zones the trades move through.

Production schedule finalization: Finalizing the production schedule requires validation, i.e., every trade needs to ascertain that their sequences are feasible and that they can perform the work in each zone to which they are assigned in the given Takt time. A sequence deemed infeasible can possibly be made feasible by "flipping" the sequence between two or more trades through zones in order to maintain the overall production schedule.

Finalizing the production schedule also provides an estimate for the planned buffer in capacity every trade in the sequence must have. This planned buffer in capacity may be used to absorb variation in the field or to help perform the work left off Takt. While the latter may enable the off Takt, "leave out" work to be scheduled more closely, the trade-off is the buffer in capacity is reduced.

TTP CONTROL METHOD

Successful execution of a TTP demands that every trade makes their hand offs, thus it is critical to control the schedule at levels shorter than the Takt time in order to gauge if the hand off will likely or not occur as planned. This creates a sense of urgency on the project (Frandson, Berghede and Tommelein, 2013). Visually communicating both performance and the plan to everyone is an important part to distributing control, identifying deviations, and maintaining the schedule.

Should one Takt time be missed by a trade, then the work for that Takt may be completed immediately with overtime, completed during the following Takt time provided it doesn't interfere with the succeeding trade, or left out. The work may be left out if the problem is unique to that particular zone (e.g., missing design details) or it can be picked up in a future task providing no work depends on it (i.e., the work cannot be structured in any other way). The reason for the miss should be researched and a countermeasure developed so as to avoid repeatedly impacting future tasks. The benefit of using Takt times to the project is that problems are identified and corrected quickly, instead of passing that production variation to the succeeding tasks.

SUMMARY

TTP requires collaboration among production team members to develop a plan deemed best for the project overall, and time to iterate from a production strategy to a detailed, feasible production schedule that is balanced. The planning first begins with gathering support from the team to proceed with TTP. Each team member then communicates their individual production system requirements and explores alternatives. Then the team works in an iterative fashion to identify the most suitable sequence, set of zones, and duration to work through the space.

DISCUSSION

Comparing LBMS with TTP shows more similarities than differences. Both methods aim for continuous flow of work through production areas at a set beat for each phase of work. Both methods also use the ability to trade scope (esp. when commercial terms encourage it) in order to improve the production system. Differences to highlight are how each method uses buffers, control, and how resources are allocated.

Construction planners can use four types of buffers: (1) time, (2) capacity, (3) space, and (4) plan buffers (workable backlog). LBMS buffers with (1), (3), and (4). Time is the preferred buffer, but space is also used when work is scheduled in areas larger than what a crew requires to complete their task productively. In contrast, TTP buffers with (2), (3), and (4). Capacity is the preferred buffer, accomplished through underloading. Space (zones) unoccupied by any trade during a given Takt can also serve as a buffer.

The two methods differ in controlling the schedule. LBMS starts with a top down approach of engineers tracking progress, running forecasts, and identifying problems that are then solved collaboratively. In contrast, TTP starts with visual workplace to make clear to all, who is doing work, and where, in order to distribute control. While the trades may provide frequent updates to the GC, they're OK to work as long as they are completing what needs to be done in the space and time allotted.

The resource allocation difference discussed here focuses on people. LBMS chooses to fully load resources on production tasks and use the same crew size continuously. The durations on the fully loaded production tasks assume optimal production rates ("optimal" here is defined as free from any causes for interference). The tasks are then buffered with time in order to maintain the productive use of people. In contrast, TTP chooses to underload crews on production tasks in order to maintain a timely, predictable hand off. Thus , people are expected to finish ahead of the Takt time, and can then work on “off Takt” work (e.g., workable backlog or leave out work), prepare for the next Takt sequence, conduct first run studies, train, or innovate to improve their work. If crews are working much too quickly, then less manpower is required to complete the production task reliably within the Takt time.

CONCLUSION

The dearth of empirical data on the use of TTP hinders a more fact-based comparison between the two methods. In order to allow for a deeper comparison, future research should gather data including:

- For each location and trade: planned and start/finish dates, resource graphs, production rates, resource consumption (manhours/location)
- days locations were suspended (no work in location)
- days tasks were suspended (no workers working on a task in any location)
- workable backlog locations / tasks, hours and dates spent on workable backlog

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COMPARING DIFFERENT APPROACHES TO SITE ORGANIZATION AND LOGISTICS: MULTIPLE CASE STUDIES

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ABSTRACT

Effective site organization and logistics is required to have an efficient production in construction projects. The same applies to the oil industry; it is absolutely necessary that the conditions are right for achieving efficient production. The oil industry and the construction industry operate under different circumstances, and have gained different experiences regarding the challenges of site organization and logistics.

Four different cases from four different firms are presented in the paper. One case is from an offshore drilling contractor in Norway. Two cases are from the Norwegian Construction industry. The last case is from a Swedish consultancy firm, specializing in site organization and logistics in the construction industry.

The case studies focus on how the different firms manage site organization and logistics to achieve an efficient production. Practices from both industries, and a generic list of lessons learned that is applicable to all construction projects are presented in the final section of the paper.

KEYWORDS

Lean construction, site organization, logistics, oil industry, construction industry.

INTRODUCTION

There are indications that the degree of innovation and the productivity growth rate has, since the mid-1990s, been lower in construction than in other industries (Produktivitetskommisjonen, 2015). Several other reports support the notion that the construction industry is lagging behind other industries in regards to productivity and reduction of waste (Koskela, 2000; Elfving, Ballard and Talvitie, 2010). Consequently, the decline in profit margins and increased competition in construction projects, forces the construction contractors to develop new ways of eliminating waste and increasing profit (Mastroianni and Abdelhamid, 2003).

Logistics to, and within, the construction site is an area with a particularly large room for improvement. A report by the Strategic Forum for Construction and

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Construction Products Association (2005) in the UK, estimates that based on evidence from other industries, cost savings of 10-30% can be achieved through effective application of logistics management techniques.

Although space needs and activity scheduling are mutually dependent, they are often considered separately (Zouein and Tommelein, 2001). Their interdependence is often ignored in the planning phase and may not be dealt with until construction is underway. Unforeseen problems identified late in the process are often expensive to remedy and can in many cases be avoided if considered at an earlier point in time. This indicates that there is a huge potential in the improvement of logistics and site organization.

In recent years, there have been several research papers addressing supply chain management (e.g. Arbulu and Ballard, 2004; Pinho, Telhada and Carvalho, 2008; Elfving and Ballard, 2013). These have focused on the flow of goods into the construction site. However, in the literature search for this paper, we found little recent research on the topic of site organization and logistics. Except for some papers that look at specific space planning tools (Tommelein and Zouein, 1993), there has been given little attention to the internal management of construction materials on site.

The paper aims to uncover effective and efficient practice for site organization and logistics on construction projects. This is done by studying three cases from the Scandinavian construction industry, where different approaches are employed. Furthermore, we also study a case from the oil and gas industry. This industry faces challenges in regards to operating in a large geographical area, while the worksites (the oilrig) are very confined. This makes an effective logistics scheme, and a carefully planned site layout, crucial for efficient production.

METHODOLGY

Construction logistics and site organization can be viewed as a result of project participants' decisions made in order to support the production. To get an in-depth understanding of this thought-process, we chose to conduct multiple case studies. Case studies are a qualitative research method that is well suited for digging deeper and gaining concrete, context-dependent knowledge (Flyvbjerg, 2006).

Projects with varying characteristics and executed by dissimilar companies were chosen. This ensured exposure to a wide variety of practices. While conducting the case studies a process of triangulation was employed. This implies using several sources of evidence to corroborate the findings in the case studies (Yin, 2013).

Semi-structured open-ended interviews were the main source of evidence in all of the cases. It was chosen to start the interviews by asking open-ended questions to avoid pointing the interviewees in a specific direction. However, a structured interview guide was also used to not leave out important aspects. By interviewing foremen, construction managers and project managers, different perspectives were accounted for.

The case studies are presented as narratives, allowing the reader to make their own interpretations. However, the main findings of the cases are summarized and discussed in the last section of the paper. Furthermore, documents such as site plans and procedures were reviewed. The last source of evidence was physical observations made by conducting site visits. The research methodology was the same in all of the case studies and the interviewees were asked identical questions to avoid bias.

RESULTS

CASE 1: HERSLETH ENTREPRENØR AS

The first case was the construction of a residential facility by Hersleth Entreprenør AS, a small Norwegian contractor. It was a design-build project with a value of 72.6 million NOK.

The forward planning was conducted in the design phase. Hersleth combined the role of design manager and project manager. This person planned the activities in a timeframe of 3-4 months prior to field execution. The production manager and foreman made a detailed activity plan, 1-2 weeks prior to field execution.

The layout of the site was planned in the design phase and remained the same for the entire construction period. The goal was to find a feasible and cost efficient layout while having easy access to water, sewage and electricity. The planned road and parking lot for the finished project was established early in the process, so that the construction work could take advantage of them. Therefore, trucks had access to the whole perimeter of the site, and could easily make deliveries exactly where the materials were needed.

Experience and routine from earlier projects was emphasized as the management's greatest asset in the planning phase. Most of the planning was done based on how it had been done on other projects. Hersleth did not operate with a separate order-schedule, but the orders were manually tracked and closely linked to the main progress-schedule. The contractor used construction drawings in an early phase to be able to order materials with a long lead-time, such as elevators.

The materials were delivered before the planned start of installation and stored temporarily on site. Efforts were made to store materials unexposed to the elements. Materials such as drywall and plywood were typically hoisted into the building per floor before the next level was added.

Hersleth had chosen to not rent a stationary crane. All of the larger lifts on the projects were related to pre-fabricated elements. These were all purchased with contracts that included delivery and installation. The supplier was also responsible for providing the crane, and brought a mobile crane on site as needed. This allowed Hersleth to carry out the remaining lifting operations at the site using only a truck-mounted crane. This was deemed the most cost efficient solution for this project.

Small make-to-stock (MTS) products, such as screws, nuts, bolts and personal protection equipment was delivered by one supplier. To avoid having to place several orders for these MTS products, vendor-managed-inventory (VMI) was implemented. The inventory of the "satellite store" was decided by the foreman and stocked once a week by a representative from the supplier.

CASE 2: VEIDEKKE ENTREPRENØR AS

The second case was the construction of a new high school. This was a public-private-partnership project with a budget of 765 million NOK. Veidekke Entreprenør AS, one of the largest general contractors in Scandinavia, was responsible for both the planning, design and construction phase.

Veidekke operates by their framework for project-based production, Collaborative Construction Management (CCM). This is an adaptation of The Last Planner System that has been used by Veidekke since 2006 (Fundli and Drevland, 2014). Site layout and logistics is an aspect of the CCM framework and is considered on all levels of planning. An overall plan for the site layout and logistics is made as early as in the design phase. However, this plan is of a dynamic character and is updated according to the production phases of the project.

When Veidekke planned the site layout for the project, they divided the construction period into six phases with six corresponding phase plans. The access road to the site and the crane, were placed so that they would avoid coming in conflict with the safety and operation of the old high school. The construction of the building was also done in such a sequence that materials could flow within the construction site without having to establish more than one access road. This was done by delaying the construction of the center of the building to allow trucks to access the back of the building through here, driving across the foundation.

Veidekke had a schedule for ordering materials, which gave information on what had to be ordered, when, and by whom. This allowed them to always be aware of lead times and critical dates. The material supplier delivered MTS items such as plywood, drywall, and steel twice a week on “milk routes”. This made it important to plan ahead, to avoid having to pay the additional cost express delivery would entail. Like Hersleth, Veidekke also employed VMI. The inventory of the “satellite store” was decided according to the phase the project was in and was stocked once a week.

To avoid congestion at the gate, caused by several deliveries arriving at the same time, they had a list with time-slots for deliveries that the trades could reserve. This was meant for deliveries that would utilize resources such as the crane or other lifting equipment.

The construction office and worker accommodations were located outside the construction site. This made receiving visitors and minor deliveries easier, as they did not have to conform to the site’s safety regulations. The minor deliveries were received outside the construction fence in a designated area.

The project management tried to get materials delivered only when they were needed – just-in-time. This was to avoid materials being in the way, taking up space and risk being damaged. However, materials such as drywall and steel were laid down on one level before the next level was added. This was done to make the lifting operations easier. Smaller materials and equipment had to be transported up the staircase by the work crews.

CASE 3: SVENSK BYGGLOGISTIK AB

Unlike the first two cases the third case does not revolve around a specific construction project nor a contractor. Rather, Bygglogistik AB acts as a third party consultant, providing logistics and material handling services for construction projects. The company builds its consulting business around a comprehensive logistics analysis. This analysis considers the parameters of the construction site and its surroundings while developing the logistics plan. The layout of the workplace and understanding how the contractor will execute the construction process is essential in the analysis. Logistics in all of the project phases, such as site preparation, framework and interior work, should be taken under consideration in an early phase. Bygglogistik emphasizes the importance of early involvement of foremen to get input on solutions that are both practical and efficient.

Bygglogistik conducts the logistics analysis using AutoCad, with additional embedded symbols and shapes. This allows them to evaluate different solutions. For example, by inserting crane radiuses they can find the optimal size, number and location of crane. The consultants also consider several other aspects regarding the crane location, such as establishing- and decommissioning-cost.

The logistics analysis is divided in two separate parts: the outer and inner analysis. Both the inner and outer analysis recognizes that the parameters of the construction site is dynamic and will therefore result in a dynamic logistics plan.

The outer analysis highlights the parameters for the construction site and the relationship to its surroundings. In other words, this analysis uncovers the possibilities and limitations that are present on the site and in the vicinity. Early planning gives the opportunity to take advantage of the area's possibilities, and mitigate the negative impacts of the area's limitations. For instance, renting space close to the site can be a good solution if there is not enough space for a laydown yard. The outer analysis must also consider disturbance to surrounding neighbors. It also considers the optimal placement of all necessary equipment to make material handling as efficient as possible. This can be visualized in a 3D-model as shown in *Figure 1*. The allocation of storage space for the various contractors is also a result of this analysis.

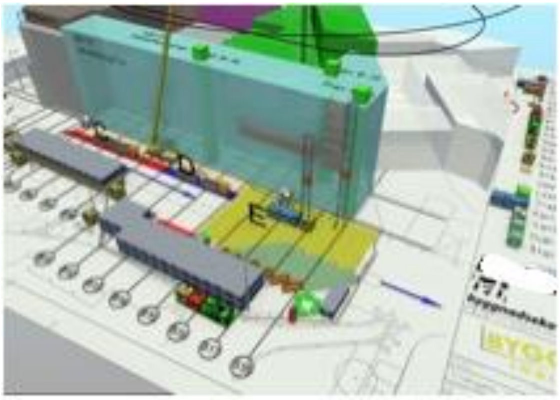

Figure 1. 3D Logistics Analysis

The inner analysis considers the flow of material from when they reach the gates of the construction site, until the final point of installation. According to Bygglogistik, aspects that are not taken into account in the planning phase can cause major added costs at a later stage in the project. Therefore, it is important to take into account both the size of the materials and the turning radius of delivery equipment. One example of a result from this analysis is to decide to design pre-fabricated elements with temporary openings to allow internal transportation of materials. Figure 2 shows a project where it was originally planned to use several construction elevators. By having temporary openings, only one elevator was required. Solutions like this can provide large cost savings.

Bygglogistik stresses early consideration of material handling. It gives them the possibility to impose certain delivery and packaging requirements on suppliers. For instance, less efficient packing results in the workers having to spend unnecessary time sorting, unpacking and distributing the windows. The window supplier can be required to package the windows on separate pallets for each apartment and in way that facilitates unpacking. This is usually no problem to arrange, if the request is made before making a purchase. However, this can be costly to arrange when the deal is done.

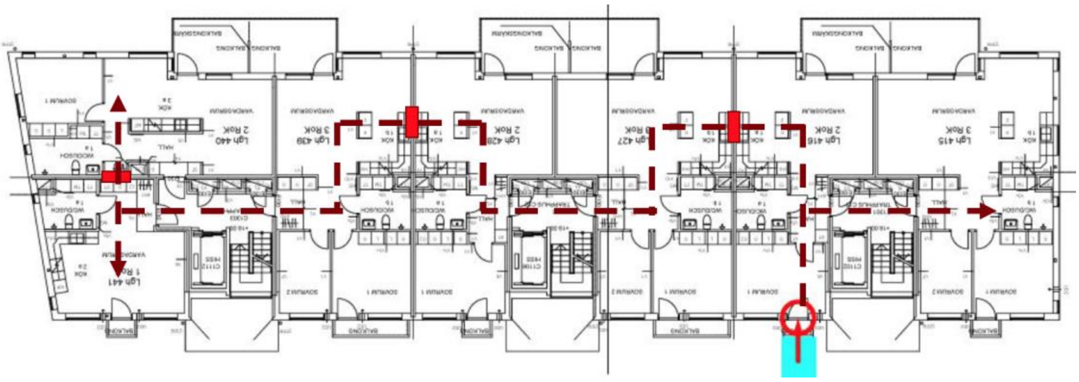

Figure 2. Design of temporary openings

Logistics Patrol is another service offered by Bygglogistik. This service comprises of the transport of materials into the building, and debris out of the building, after regular work hours. This means that the construction workers can focus on their trades, not performing material handling, and that the production will not be interrupted by material deliveries. Bygglogistik focuses on carrying out the work as economically as possible so that the customer will benefit. After finishing the job, the patrol creates a report informing of what has been done, and any damage occurred during delivery from the factory or occurred during the internal handling at the construction site.

Bygglogistik has developed a web-based software called LogNet for managing deliveries to the construction site. LogNet schedules the deliveries and provides a real time update of when they are arriving at the site. All users with access are able to check which unloading resources are available in a given time period. Everyone who is responsible for ordering materials to the site have access to this tool, and have to apply for a time-slot for their delivery. The time-slot has to be booked at least five days in advance. The administrator, usually the logistics manager, has to consider if the required resources are available. Based on the availability, the request is either accepted or a new time-slot is suggested.

All deliveries must be called-in by the driver 30 minutes prior to arrival at the construction site. When the materials arrive at the site the logistic manager will register them, and the responsible person will be notified by receiving a text message from LogNet. The materials will then either be picked up by the contractor or temporarily stored until the Logistics Patrol arrives in the afternoon. The logistics manager has a standby system with a dedicated parking area for delayed deliveries, and accepts the deliveries when the handling resources become available.

Bygglogistik was hired as a consultant and responsible for material handling in a residential project in Gothenburg with 162 apartments. The contract value of the project t was 160 million SEK. The marketing manager stated that the total achieved savings due to working efficiently with logistics was 16,000 working hours compared to what was estimated in the tender agreement. The total savings incurred for the project amounted to approximately 5.6 million SEK. The consulting and material handling cost for using Bygglogistik was approximately 2 million SEK. Total cost savings incurred by the developer was thus 3.6 million SEK.

CASE 4: SONGA OFFSHORE

The last case is from the oil and gas industry. Songa Offshore is a Norwegian drilling contractor founded in 2005. The company presently operates a fleet of three midwater semi-submersibles, but an additional four are being built and will be delivered within 2015. Songa Offshore is Statoil's largest drilling services provider operating in the harsh environment of the North Atlantic Basin (Songa Offshore, 2013).

One of the major challenges in regards to logistics in the offshore oil industry is the distance from the material supplier to the location of the oilrigs. The harsh weather conditions are also a factor that has to be considered. Scarcity of storage space on the oilrigs, long lead times on material orders, and large distances makes an effective logistics system a necessity to achieve efficient operations. Material handling onboard the oilrig is also a major challenge, and a field where there is great potential for improvement. One of our informants claimed that drilling for oil is about 90% logistics, making it extremely important to streamline this.

Many components that are crucial to the operations offshore have long lead times and it is therefore important to have spares, in addition to a buffer of consumables. While the most critical parts are stored on the oilrigs, most of the materials are stored at the base onshore. The base is also where deliveries from suppliers are made, repackaged and shipped offshore to the oilrigs. There is an advanced ERP-software in place, which comprises several functions, to keep up with maintenance needs. It alerts when maintenance is to be performed, produces a list of required materials, makes a work order request, orders the required materials and the transportation of them.

Limited space on the supply vessels, low frequency of shipments and weather conditions make forward planning and coordination with the operations team critical. If, for some reason, the necessary equipment has not been delivered on time, or spare parts are not readily available, the drilling contractor risks losing several hundred thousands of dollars in revenue. In such cases, the contractor goes to great lengths to get the parts. In some cases this even means chartering a helicopter to deliver a single piece of equipment. Therefore, there has to be a balance between just-in-time deliveries and buffers, being that the stakes are so high.

When supply vessels arrive at the rig, the deck crew operates offshore cranes to hoist the materials onboard. The containers are placed on deck according to where the materials are to be utilized and to optimize the deck space. The storekeeper makes sure that all the containers on the manifest are delivered, following a careful inspection and registration of the materials that have been delivered. Thereafter the person responsible for the order is informed that the materials have arrived.

The crew working on deck serves as a support function for the drilling crew, being responsible for all the logistics on the rig. Ideally they should have parts ready for delivery to the drill deck when they are needed. However, this isn't always the case. The ongoing operations on the drill deck is not very transparent, making it difficult for the deck crew to plan ahead and place materials in a logical manner according to drilling progress. This results in unnecessary material handling, which consumes resources in the form of labor and lifting equipment.

Based on decades of experience there has emerged a consensus viewing drilling operations as the handling and movement of parts and equipment. While the newer oilrigs are optimized for efficient material handling, the older rigs have several areas and rooms that are not accessible with crane, truck or elevators. The design of the new Cat-D rigs, which Songa has under construction, is tailored for efficient material handling. Flushed decks makes the entirety of it accessible with a forklift truck, and heavy equipment is moved on a tailored skidding system. Offshore cranes will handle heavy lifts on deck and to supply vessels, while elevators between the levels make the flow of materials within the rig more efficient. According to NORSOK Standard, "The installation shall be designed to ensure that the number of lifting operations is minimized" and "to facilitate use of fork lift truck or trolley, all transportation routes shall be planned without any obstructions or thresholds." (Norwegian Standard, 2012) The goal is that this new rig design will be 20% more efficient than conventional rigs (Statoil, 2011).

Furthermore, there is great potential for developing and implementing software to streamline logistics and material handling. The idea is to utilize computer advanced visualization tools (CAVT) to make the needs of the drill crew more transparent. Because the drilling operation is planned in 15-30 minute intervals it is possible to also plan the logistics down to this level of detail. The crew on deck would then be able to place equipment strategically to effectively accommodate the drilling operations while optimizing space usage and minimizing lifting operations. Also, by virtually placing the equipment and parts on a 3D-layout of the rig, the crew is able to keep track of where the equipment is at all times.

DISCUSSION

In construction, materials are ordered, transported, delivered, stored, moved around, and processed before final installation. These steps should be made as efficient as possible. Steps such as moving and temporarily storing materials at the construction site are waste (Koskela, 2000), and should ideally be eliminated altogether.

Material handling within the construction site should be a priority on all projects. However, we found this to be lacking in some of the cases. Previously, in the oil and gas industry, this was barely a consideration while now it is one of the most important aspects of rig design and operations. Based on our observations, we believe the construction industry could potentially achieve great improvements in production. This will likely require that the efficient flow of materials within the site is considered far earlier on in the project than what now is typical. Solutions like the temporary opening in the pre-fabricated elements that we saw in the Bygglogistik case are only possible if they are considered as an integral part of the design process.

Planning the site layout, logistics, and allocating the proper resources are essential for an efficient production. There are clear differences in how these aspects are managed in the cases reviewed. Bygglogistik and Songa Offshore use ample resources to plan the layout of an effective production area. Hersleth seems to consider logistics as a field that can easily be managed using previous experience. We believe this business-as-usual attitude may limit the opportunities for improvement, and that a more structured approach, like the framework Veidekke performs by, is required.

The flow in production should never stop due to lack of materials. However, this does not mean that all materials should be ordered as early as possible and stored on site, but rather that they should arrive just-in-time on site. A balance between material buffers on site and just-in-time deliveries should be evaluated based on certain conditions: distance to supplier, lead time, level of detail in the plans, and amount of storage space on site. Buffers should be larger if these conditions does not favor the contractor. Naturally, there will need to be larger buffers on an oilrig offshore compared to a rural construction site.

All the companies had different approaches regarding the process of ordering materials. They all identified material requirements in the forward planning, but on different levels of accuracy. The cases with a structured delivery schedule with material lead times, critical order dates, and person responsible minimized the risk of forgetting materials. However, there is a clear potential for further improvement in the construction industry, by learning from the detailed planning done in the oil industry.

Delivery from material suppliers is another area of improvement, which can increase the efficiency. The delivery requirements for the material suppliers should be thought out and clear. Bygglogistik negotiates efficient delivery and packaging solutions during procurement to avoid having to pay an extra fee for this later in the construction process. This provides savings in terms of time and cost.

Implementing software can greatly contribute to managing logistics and creating transparency for stakeholders. LogNet, employed by Bygglogistik, is a good example of this. The software creates transparency for project participants by providing real-time information about when materials are arriving and which handling resources are at their disposal. Songa's idea for CAVT-software and their ERP-system is also a good example of software that contributes to efficient operations and production.

We believe that all projects could benefit from better management of logistics and site organization. However, it seems clear that the projects with difficult conditions like limited space, poor transparency and a congested environment will have a greater room for improvement. Hiring a company like Bygglogistik on a small rural project would likely be overkill, the cost would outweigh the benefits. On the other hand, using a structured approach, like the one employed by Bygglogistik, might be necessary for a large complex urban project.

CONCLUSION

Based on the findings from the cases, which are discussed above, it is clear that site organization and logistics is managed differently in the oil and gas industry compared to construction. It seems that the construction industry can learn from the oil industry in regards to managing their production as a flow of materials. Achieving efficient logistics to and within the worksite is a substantial contributor to efficient operations, which is also the case in the construction industry.

With regards to how site organization and logistics should be approached, there are four points that we found to be relevant to all projects:

- Site organization and logistics should be planned at an early stage
- Software tools are beneficial in managing site organization and logistics.
- A structured approach is necessary for optimal performance
- The approach has to be tailored based on project complexity

In this paper, we have barely scratched the surface on the topic of site organization and logistics in construction projects. Based on what we have found of literature on the topic and our findings from the cases, this is clearly an area that warrants more in-depth research in the future.

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INSTANTASK: DESIGNING A VISUAL APPLICATION FOR ENABLING AGILE PLANNING RESPONSE

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ABSTRACT

In modern construction projects, reliable planning is of paramount importance. However, despite good planning practices, new tasks not mentioned on the lookahead schedule frequently appear during the week of execution. These new tasks are an added burden to the work plan and will ultimately impact construction workflow. The purpose of this paper is to introduce the concept of "Instantask", as a mobile application addressing this problem. "Instantask" attempts to facilitate an agile response to these unplanned tasks by making them visible to its users as soon as they are noticed and recorded. The users represent all concerned project participants: managers, site engineers, foremen, and tradesmen. The proposed application aims at enhancing fast, clear, and effective coordination between users to mobilize the action plan needed to address these new tasks on site. Additionally, the application will track and document the emergence of these tasks to improve future planning activities. The paper presents a prototype user interface of the application. The benefits of using "Instantask" are tested by conducting a social network analysis comparison via SocNetV. The paper highlights that firms already adopting lean construction practices or those companies in the beginning stages of implementing them would greatly benefit from this application.

KEYWORDS

Instantask, visual management, new/emergent tasks, lookahead, Last Planner System.

INTRODUCTION

Modern construction projects face the constant pressure for shorter durations and risk complexity and uncertainty throughout their life cycle (Koskela, et al., 2002). And the challenge in modern projects lies mainly in the difficult coordination of activities and tasks. In modern construction projects, implementing a Last Planner System (LPS), which is a production planning and control system, is an essential method to increase

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the workflow reliability (Hamzeh, 2009). LPS will help reduce the complexity and uncertainty of tasks scheduled in the lookahead planning and weekly work plan. However, problems in any planned schedule arise when new tasks or unforeseen changes appear at the week of their execution on site. These new tasks emerge during the week execution of the previously planned activities. Proceeding in the tasks execution without full removal of constraints is a main reason behind the appearance of new tasks (Hamzeh, et al., 2012). For instance, having constraints on site can be related to uncertainty, lack of planning, lack of information, or pressure for fast action (Hamzeh, et al., 2012). These tasks require a significant effort to execute them and hinder the overall project progress. In such cases, adhering to the initial schedule set will be very challenging.

Having an agile response to these unforeseen tasks is a potential solution to this frequent problem. According to Hamzeh, et al. (2012), shortening the communication time between the site and the decision making entity is a must in order to increase agility and quick responses to unexpected problems.

In this paper, the concept of a visual application will be introduced as a solution to this problem. The application will try to enable a flexible response to these unplanned tasks by making them visible to all. The paper will investigate how making new/emergent tasks visible would encourage a collaborative effort and facilitate coordination between all parties to these unplanned tasks more effectively and in a timelier manner. In addition to reporting, the application would also document the emergence and the evolution of these problems, which facilitates learning from previous experiences and preventing and/or resolving more effectively in future projects. The features of the application will include:

- Report new/emergent tasks that are in scope but had not been pre-identified due to bad short-term planning
- Make these tasks visual to facilitate agile response by whoever is free and is using the app
- Document these emerging tasks to promote learning and prevent similar tasks from being unforeseen in the future

This research paper will present the prototype user interface of the visual software and its key features mentioned above. It is important to note that when discussing new tasks that arise on site, the terms “new task”, “emergent task” and “new/emergent task” are used interchangeably in this paper.

LAST PLANNER SYSTEM (LPS) AND NEW/EMERGENT TASKS

For the purpose of the application, the most relevant planning levels in the LPS are the lookahead and the weekly work plans. The lookahead plan process is concerned with the breakdown of tasks into the operations level, identifying constraints, and removing constraints by assigning activities for the operations execution plan (Ballard, 2000). The corresponding time span of the lookahead planning varies between 2 and 6 weeks. As for the weekly work plan process, it mainly deals with the work assignments for a week’s time. It is important to note that it is at the levels of the lookahead planning and the weekly work plan in particular that the problem of new/emergent tasks appears. At the week of execution of planned construction tasks, new/emergent tasks are added to the weekly work plan. These tasks are considered to be part of the original scope of work, but that had not been identified due to lack of foresight at the lookahead planning level. This means that they have not been broken down or made ready systematically. Consequently, they are assumed to require additional effort to execute, and will hinder the progress of the workflow more, compared to tasks that had been foreseen and broken down normally (Hamzeh, et al., 2015). The cause of the emergent tasks can be related to failure to account for the necessary prerequisites to complete a certain job, or failure to clear all of the constraints affiliated with a specific task. It is important to note that these new tasks are of the same "granularity", or level of detail, as the tasks in the weekly work plan, and thus can be incorporated into it.

STATE OF THE ART IN LEAN CONSTRUCTION SOFTWARE

Table 1 presents several lean construction software that were surveyed, along with their features. This list is not intended to be comprehensive, and emphasis was placed on more recent software, especially applications that offer a mobile companion app.

Table 1: Lean Construction Software

Application	Functionality Description
Kanbanize; Kanban tool; SwitftKanban	• Process Visualization • Workflow Management • Communication and collaboration with different parties • Analytics and performance tracking • Mobile companion application available
LeanKit	• Features similar to those of Kanbanize • Real-time schedule updates using Primavera P6 integration
SimpLean (Faloughi, et al., 2014)	• Features similar to those of Kanbanize, excluding analytics • Display of task constraints and maturity • Drawing viewer • Simple user interface intended to facilitate adoption
KanBIM (Sacks, Radosavljevic and Barak, 2010)	• Display of task location by overlaying Kanban cards on BIM • Display of work packages, task constraints and maturity • Focuses on the control workflow
VisiLean (Dave, 2013)	• Features similar to those of KanBIM (with BIM integration) • Focuses on production planning and scheduling
RCM-Plan (González, Alarcon and Ulloa, 2010)	• Prediction of project participant performance • Multidimensional interactions' view of several production parameters
WorkMovePlan (Choo, 2013)	• Display of work package, space scheduling, and constraint information • Automatically updating shared schedule • Planner can explicitly allocate space, including workspaces, laydown areas, storage areas, access paths on a daily basis

THE NEED FOR A NEW TASK REPORTING TOOL

Currently existing lean construction software has thus far focused on providing systems to optimize execution of planned and well-defined tasks, and on making these systems visual and collaborative (Sacks, Radosavljevic and Barak, 2010). However, while the solutions for these aspects are well developed, there has been no dedicated solution offered to the specific problem of mitigating or enabling an agile response in real-time to the emergence of new tasks. Nor has there been a tool that is explicitly designed to require a very small barrier to entry (in terms of usability) and minimal effort to keep using it. There is a need to address this gap because some tasks are so critical that even a response at the weekly level is too late, and thus they require a real-time response.

RESEARCH METHOD

This paper proposes a new visual management application that presents a solution to the problem of emergence of new tasks in the construction industry. The specific aims behind this research are: (1) understand the conditions (when and why) in which this tool can be used in the construction industry, (2) develop the prototype user interface of the application, (3) introduce and describe how this tool can be used, (4) assess the benefits of using the proposed application.

To meet these objectives, the research process consisted of review of relevant literature, examination of numerous and diverse mobile applications, development of the application's user interface, and evaluating the effectiveness of the proposed solution. The survey of various lean software applications familiarized us with the presentation aspects and user interface features of mobile applications. The evaluation of the application's effectiveness consisted of a social network analysis of a hypothetical case modeled using the software "SocNetV".

THE APPLICATION

OVERVIEW OF INSTANTASK

As previously mentioned, Instantask is a visual mobile application that aims to facilitate an agile response to emergent tasks. Specifically, for a given emergent task, it will do this by: (1) making the new/emergent task visible to all users, (2) identifying the task's constraints, (3) identifying the owner(s) of the constraints, (4) assigning the task to the owner(s) of its constraints, (5) integrating the new/emergent task into the weekly work plan, (6) monitoring and updating the task's status.

Instantask also aims at promoting learning for improved future project performance; this objective is accomplished by collecting data to be reviewed by project participants.

Keeping the app simple is vital to ensuring user engagement, compliance, and continued use. So we conceived of an app design consisting of a single page view. This page will contain a list of new/emergent tasks, sorted by their importance. Newly emergent tasks that are on the project's critical path are shown at the top of the list, and tasks that have been marked as completed are shown at the bottom. The main screen will also display each task's deadline. The color-coding of the tasks and their position on the screen is further explained in Table 2. In Instantask, each task is described in terms of its status (critical/not critical), deadline, location, its "appearance time and date", the person who reported it, its constraints, the owners of its constraints, and its parent task. The parent task is the task from which the emergent task is derived, and is on the level of lookahead planning rather than weekly work planning. When the owner of a task's constraints is identified and entered in a task's description, that user is "tagged", and receives a notification that a new task has been added to his/her list of tasks. Further, whenever possible, the task will also contain a brief description. Users can access this information by pressing on the task's icon in the main screen. Any user can add a new task by pressing an appropriately located "+" button. Each user will have a separate username; this is to facilitate collaboration and enhance the social aspect of construction and to open up possibilities for other features, such as messaging. Users should indicate on the main view whether they are available to work. This status will communicate whether a user is "Available" or "Busy". If a new task is posted to the system, available users will get a push notification. Furthermore, if a new task is posted to the system, and this task is on the critical path, all users will receive a push notification (even if their status is "Busy"). The criticality of a new task is assessed and indicated by an automated check of the parent task's criticality.

The users of Instantask are Last Planners of all kinds: foremen, general foremen, superintendent, site engineer, section engineers and managers. However, for the purpose of the application, there are two types of users: (1) Site (non-management) users, denoted by "Site", (2) Management users, referred to as "Management". When a new task is completed any user can mark it as such. However, before it can be removed from the system, a Management user should approve this "completed" status.

Table 2: Status Description of Every Task

Status	Color Code	Position in Main List
Critical, not completed	Red	Top
Not critical, not completed	Blue	Middle
Completed, not approved	Green	Bottom
Completed, approved	N/A	Not in list

COMPONENTS OF USER INTERFACE

Main Screen

The application launches to the Main Screen. The main screen, as shown in Figure 1 below, is common to all users of the application and simply displays the new/emergent tasks documented. These are sorted according to criticality first, according to Table 2, and within each criticality level (i.e. within each color), the tasks are sorted by deadline (nearest first). On the main screen, users can choose whether to display all new/emergent tasks ("All Tasks") or only the tasks that they have been tagged in ("My Tasks"), by swiping the top layer where this designation is displayed. In addition to viewing the list of existing tasks, users can add a new task, tap on an existing task to edit it or view it in greater detail, and/or change their status ("Busy" or "Available") via the green slider in the bottom right corner. Also, users can access peripheral features such as task search, and analytics, using the appropriate buttons in the top right corner of the main screen. These features will be described in the "Peripheral Features" section.

Add/Edit/View Tasks Screens

When a user adds a new task by touching the large "+" button, the application goes to the "Add New Task" screen. Here, the user inputs a short, descriptive task name, the parent task from which the new/emergent task derives, the task location (e.g. 3rd floor master bedroom), the task's constraints, the project participants responsible for these constraints, and any additional details the user might find relevant.

When a user adds a new task, he/she will have to choose from a list of parent tasks that is fetched automatically from the project main schedule. If the parent task is on the critical path, the task being reported immediately and automatically gets its status set to "Critical". Moreover, the task's deadline is also set accordingly.

The application will automatically fill in information about who reported the task and the date reported, since every user will have a unique username and profile.

Once a task is added to the system, it becomes visible to all users of the application. Clicking any task on the main page will lead to the "View/Edit Task" screen. This page shows task name, parent, location, and description as input by whoever reported the task, as well as the automatically generated entries "Date Reported" and "Reported by". It also contains additional information about the task criticality and its deadline according to the schedule. Moreover, it contains sections dedicated to task constraints and the people responsible for these constraints, or the constraints' "owners".

Any user can edit this information by touching the "Edit" button in the upper right corner of the screen. In this way, information will accumulate regarding a task's constraints and their owners. At the bottom of the page is the option to mark a task as "Completed". Any user can do this; however, a task is only removed from the main screen if a Management user has confirmed that the task is completed.

PERIPHERAL FEATURES

Analytics

In order to promote learning from planning oversights so that these are not repeated and planning performance can be improved, Instantask will collect data regarding new/emergent tasks. This data includes grouping the tasks by function (e.g. MEP, Masonry), by parent task, and by constraint. These groupings could help to identify problematic areas and prioritize their targeted improvement. For example, if in a given week, 10 new tasks were reported, and 5 of these tasks were constrained by the same constraint, then it would be apparent that the removal of this constraint ahead of time in future weeks would enable a more timely response to resolving new tasks as they appear. The same logic applies to parent tasks and functions.

Further, Instantask will sort new tasks by the time taken to resolve them. This, combined with the grouping options mentioned above, could guide prioritization of elimination of these planning failures. Furthermore, in the event that the same planning failures were to be repeated, this sorting could help in selecting which of the new/emergent tasks are to be executed first. For example, if in a given week, MEP-related new tasks required 6 hours to resolve, whereas masonry-related tasks required

2 hours, then it would be apparent that MEP-related planning failures should be addressed first. Moreover, if they are not addressed, and MEP-related planning failures do recur in the next week, then it would be evident that these need to resolve before masonry-related new tasks are resolved.

Finally, Instantask will gather information concerning user proactivity, for example, which users report the most new tasks, and which users resolve the most. This could help to identify top performers and could inform workload allocation.

Search

Instantask will have the ability to do a project-wide search of tasks. The search will return results based on keywords; users can search by parent task, location, tagged users, and task name. For example, entering a specific user's name in the search bar will return all the tasks in which that user has been tagged.

FLOW OF USE

The flow of use of the application is demonstrated in Figure 1 below. The figure illustrates an example of two typical use cases, namely: adding a new task and marking a task as completed. In the case of "Adding a new task", the steps required are:

(1) The user sees a new task (Task 6) on site and presses the Add Task button ('+'), on the main screen, to report it. This takes the application to the Add Task screen. (2) In the Add Task screen, the user inputs details about the task, as shown in the figure. Then, the user presses the "save" button, which returns the application to the main screen. (3) The main screen now includes Task 6. Its criticality (critical, as indicated by the red color) and deadline (June 27) have been fetched automatically from the project main schedule, since the user reported Task 6's parent task. The remaining tasks have been displaced, and can be accessed by scrolling downwards.

As for subsequent case of "Marking a task as completed", the steps involved are:

(4) The user has learned that Task 1 has been resolved. From the main screen, the user presses on Task 1, which takes the application to the View/Edit Task screen. (5) In the View/Edit Task screen the user presses the "Mark as Completed" button at the bottom. This returns the application to the main screen. (6) The main screen now shows only 2 unresolved critical tasks. Task 1 is now marked as "completed", as indicated by its green color and position at the bottom of the screen. It will remain visible until a Management user confirms that the task has indeed been resolved.

SOCIAL NETWORK ANALYSIS VIA "SOCNETV"

ANALYSIS METHODOLOGY

To examine the impact of Instantask on information flow within a project, a social network analysis was conducted. It is important to note that this analysis is of a hypothetical project, since the application has not yet been developed.

A typical project was assumed with the following agents (represented as nodes):10 crew leaders (nodes 1-10); 4 site engineers (nodes 11-14); 1 project manager (node 15); and 1 construction manager (node 16).

The links between nodes represent information flow between agents. This information is any form of communication, for example, a site engineer assigning a task to a crew through its crew leader, or a site engineer sending a progress report to one of the managers. Two scenarios were analyzed: one base case and one scenario in which Instantask was used.

Figure 1: Instantask Flow of Use

In the base case, each engineer is connected to every other engineer, to the PM and CM, and to 4 crew leaders. Further, the PM and CM are connected to each other. However, the crew leaders are not connected to each other, reflecting the trade split organization that often occurs in projects. As is often the case in real projects, there is no direct link between crew leaders and either the PM or the CM; information must first pass through an engineer.

In the Instantask scenario, the network is a complete network; that is, every agent is directly connected to every other agent. This follows from the assumption that all project participants will have a smartphone and can therefore access the application. A visualization of each resulting social network is presented in the Figure 2 below.

Analysis Results

The results from the social network analysis are best interpreted qualitatively. In the Instantask scenario, previously unconnected project participants became directly connected. In the base case, information must travel through an engineer to reach management from on-site crews, and vice versa. Instantask provides a way to skip the middleman if need be, giving information more freedom to travel by giving it more avenues. Furthermore, by using Instantask, the average number of links per user increases. The resulting higher degree of connectivity could potentially translate into timelier reaction to and resolution of new/emergent tasks.

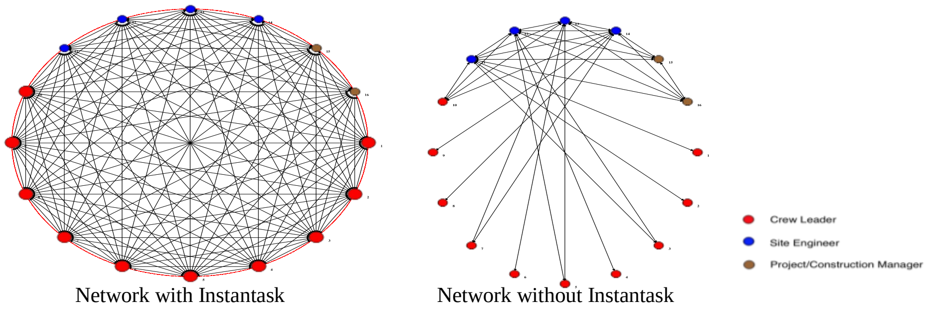

Figure 2: Results of Social Network Analysis

Finally, using Instantask decentralizes the project network. In the base case, some nodes had been central to the network; these nodes correspond to the site engineers through whom information must flow because the managers and crew leaders were not connected. This flattens the structure of construction projects, which is typically hierarchical, and increases the transparency between the concerned project participants. Figure 3 provides an illustration of this.

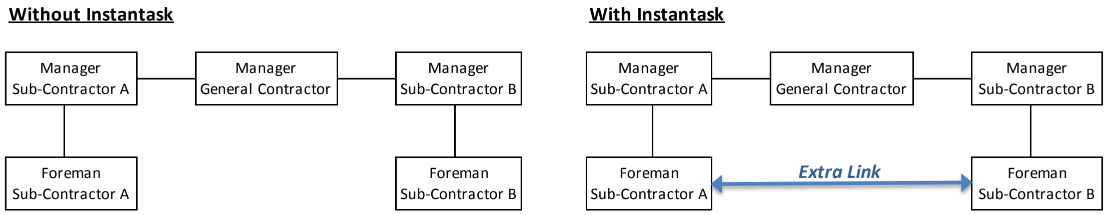

Figure 3: Illustration of the Benefits of Instantask

Because new tasks are assumed to require an extra burden to execute compared to normally broken down tasks (Hamzeh, et al., 2015), their accumulation can contribute disproportionately to project delays. Making them visible to all project participants immediately after they are reported (rather than delayed) increases the probability that they are dealt with promptly and effectively, thus decreasing their probable disruptive impact on project workflow. According to Hamzeh, et al., (2012), accelerating the communication time between site and decision-making entity can be achieved by delegating more authority to blue collar workers. This would increase quick response to deal with new/emergent tasks. Additionally, documenting their emergence and other data concerning them, as mentioned in the Analytics section, would serve to highlight key areas of improvement. This information provides a database for organizational learning, which would improve lookahead planning capabilities and thus decrease the expected number of new/emergent tasks in future projects.

CONCLUSION

While the work presented herein represents a step forward, there is still much work to be done. The analysis consisted of a theoretical examination of the benefits of incorporating a task-reporting tool, namely Instantask, using social network analysis. This analysis is presented in lieu of field data, as the mobile application has still to be developed. Once development of a working prototype has been completed, a pilot case study should follow in order to determine the application's effectiveness, as well as to identify its shortcomings and address them for future iterations and the final version. This entails the selection of an appropriate project to use in the case study. Moreover, from a technical standpoint, the back-end software and hardware requirements still need to be addressed. The proposed system implies a project-specific nature, such that each user will need to be assigned to a project that is to be identified in advance. As such, each project may need to be allocated its own dedicated server. These details and other implementation details will be addressed once the application working prototype has been implemented.

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A BIM-BASED FRAMEWORK FOR MATERIAL LOGISTICS PLANNING

Jack C.P. Cheng[1] and Srinath Kumar[2]

ABSTRACT

Material logistics planning (MLP) is an important component of supply chain management that promotes tidy construction sites and efficient project delivery. It aims to ensure that the right materials and equipment are delivered to site at the right time so as to reduce the idle resources and space requirement on site. Therefore, MLP can support lean construction as it can reduce unnecessary transportation and material handling, which are regarded as waste. However, supply chain issues such as late or incorrect material delivery are still common on construction sites nowadays. This paper presents and demonstrates a framework based on building information modeling (BIM) for automated material logistics planning and management. Using the Revit Application Programming Interface, we developed a system framework that extracts geometric and material information from BIM models and integrates the information with schedule information for formulating a dynamic construction site layout model. Material delivery and storage information is made available to supply chain members for planning and monitoring purpose. Our framework also considers the interior space inside the buildings under construction, which is important for construction sites with limited available space. A case example is demonstrated to validate the framework and demonstrate its potential for construction management.

KEYWORDS

Automation, building information modelling (BIM), lean construction, logistics, site layout planning.

INTRODUCTION

Supply chain management (SCM) in construction projects has been studied in various research efforts (O'Brien, et al., 2002; Oakland and Marosszeky, 2006; Cheng, et al., 2010). However, an important but fairly less studied aspect of construction supply chain management is the material logistics and layout planning on construction sites, which deals with coordinating the material requirements of a construction site so as to minimize waiting time, double handling, and delays related to material deliveries. Thorough planning of the construction site layout, monitoring of site level activities, and continuous coordination with material suppliers is extremely vital in ensuring a

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well-coordinated material logistics plan (Pryke, 2009). Most studies on site layout planning use the planned construction schedule as a basis to determine – (1) the temporary facilities required for storage, (2) the time interval for which they are needed on the site, and (3) optimized locations for setting up facilities so as to minimize on-site transportation distances (Zouein, et al. 1999; Ma, Shen and Zhang, 2005). However, in most projects due to variations in construction times and supply chain uncertainties, the schedule undergoes modifications once construction progresses. As a result the site layout plan initially formulated around the construction schedule becomes unfeasible to implement. The site layout plan then serves only as a rough guide, with most of the governing decisions being made by the site superintendent. As a result, the planning effort is wasted and eventually leads to unplanned site layouts. In urban construction projects, due to the confined nature of the construction site, the site layout and material logistics plan have to be carefully coordinated in order to ensure a smooth workflow (Said and El-Rayes, 2013). Incorrect deliveries and stockpiling of materials on site lead to overcrowding of the workspace and can be seen as hazardous as well as contributing to operational inefficiencies. Large travel distances between material storage and installation areas, double handling of materials and overcrowding of the site due to improperly coordinated deliveries are common examples of operational wastes generated in urban construction projects due to a lack of planning (Said and El-Rayes, 2014). In order to facilitate lean construction, it is important to eliminate the occurrence of these inefficient practices. However, constrained site conditions, tight schedules and various material requirements of contractors make coordination of material deliveries an arduous task. The complexity of this problem is compounded with the addition of delays in deliveries and construction activities. In this paper we aim to develop a construction site material logistics system to aid in coordinating material deliveries on confined construction sites, thereby decreasing waste and supporting lean construction. Our framework addresses a key missing component of current material logistics systems, by addressing site layout planning not just on a strategic and tactical level, but also on an operational level. As a result the site layout can be properly coordinated with material logistics in order to facilitate lean construction.

Our framework consists of four modules - (1) construction progress monitoring module, (2) construction site space estimating module, (3) material delivery coordination module, and (4) material storage optimization module. By leveraging information from BIM models and construction schedules, we are able to automate several of the calculations required for our analysis. Material information is extracted from the BIM model and linked to the construction schedule to create a resource-loaded schedule. The resource-loaded schedule is used to estimate the consumption of materials, and forms the basis for planning the logistics of material delivery and storage. Another important feature of this framework is that it also considers interior storage spaces within the building under construction. In many urban construction projects, due to limitations in site space, materials and equipment may be temporarily stored on each completed floor of the building. In such cases it is extremely important to evaluate the storage requirements and availability ahead of time in order to avoid wastes associated with material double handling and conflicts with construction activities. The following four sections describe the framework in detail and also present a case example for validation.

THE BIM BASED MLP FRAMEWORK

The BIM-based MLP framework consists of four modules - (1) construction progress monitoring module, (2) construction site space estimating module, (3) material delivery coordination module, and (4) material storage optimization module.

CONSTRUCTION PROGRESS-MONITORING MODULE

A construction schedule defines the start and end dates of each activity comprising the construction project, thereby serving as a blueprint for the project. A resource-loaded schedule, in addition to activity starts and end dates, also contains information about the quantity of materials needed by each activity. It is important because it can tell us the quantity of materials that are required during different stages of construction, thereby serving as a basis for planning the material logistics of a construction site. Construction projects however, seldom stay on schedule, with many activities taking longer to complete than estimated. As a result, material logistics cannot solely be based on the planned construction schedule. The progress of each activity and its projected completion date must be evaluated before planning the material logistics. Delays in construction activities will otherwise result in excess materials being stored on site and may lead to site crowding or congestion (see Figure 1).

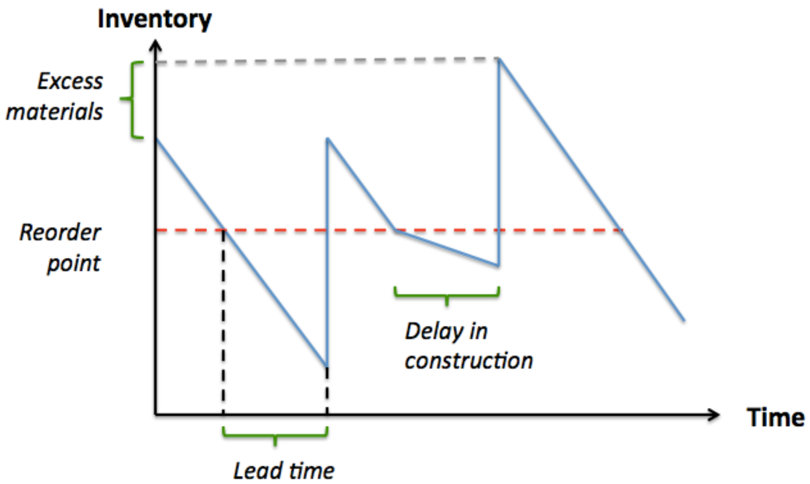

Figure 1: Delays in construction activities leading to excess materials being stored on site

As can be seen in Figure 1, delays in construction would result in a decreased rate of material consumption. Thus, in a given time interval, fewer materials would be consumed than was planned, leading to larger level of inventory. Construction sites with limited space may not be able to accommodate larger material inventories and as a result extra materials would have to be accommodated in temporary storage areas. In our study, the construction progress-monitoring module is used to estimate the progress of activities and estimate their completion dates. This can be done by breaking down each activity to terminal activities carried out on the construction site. Take for example the activity “1st Floor Column No. 01”, the activity associated with constructing a reinforced concrete column on the first floor. As shown in Figure 2, the activity can be subdivided into erecting formwork, arranging reinforcement, pouring concrete, curing and stripping off formwork.

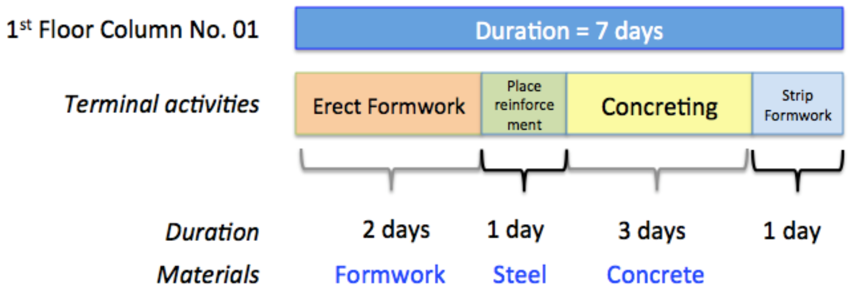

Figure 2: Splitting up of an activity into terminal activities

Our system requires users to input the status of each such terminal activity, on a daily basis. Based on the input our system calculates the delay in each terminal activity using the following equation.

$$t_{d,i} = t_{f,i} - t_{s,i} - d_i \tag{1}$$

where $t_{d,i}$ refers to the delay, $t_{f,i}$ is the finish date, $t_{s,i}$ refers to the start date and d_i refers to the planned duration of the terminal activity i. A positive value of $t_{d,i}$ refers to a delay whereas a negative value indicates that the terminal activity is ahead of time. The delay in an activity is equal to the sum of the delays in the terminal activities that it comprises of, and can be calculated using the following equation.

$$T_{d,n} = \sum_{i=1}^{m} t_{d,i} \tag{2}$$

where $T_{d,n}$ refers to the delay in activity n, which comprises of m terminal activities. If there is a delay of 1 day in arranging the reinforcement, we can thus predict that the activity will be delayed by 1 day. This however assumes that more labour is not allotted to the activity to ensure faster completion. The construction progress-reporting module continuously updates the progress and subsequently predicts the completion date of each activity on the construction schedule. The splitting up of activities also facilitates the creation of a resource-loaded schedule. Material information is extracted from the BIM model and linked to the corresponding activity. For example, the terminal activity "arrange reinforcement" is linked with the quantity of reinforcement from BIM model. In our study we use the Revit Application Programming Interface (API) to automatically extract these material quantities and link them with the schedule, which is stored in the csv format. However, automatically linking tasks on the schedule to their corresponding elements in the BIM model is not an easy task. For this reason, we used a naming convention for BIM elements and scheduled activities. This was defined as an additional attribute for each member in the BIM model, which could be read by our program to automate the creation of a resource loaded schedule. In this manner, the schedule indicates not just the activities start and end dates, but also the material consumption pattern. The construction progress report along with the resource-loaded schedule forms the basis of planning the material logistics. However, this framework has certain limitations. Firstly, the granularity or level of development of the BIM model, should match the level of detail in the construction schedule. Secondly, the reporting of construction progress, and amount of materials used, would have to be performed frequently and with a high level of accuracy. Although this may be tedious, having accurate daily reports of construction progress and materials used, allows the sub-contractor to better assess their performance, facilitating a lean process. It will help sub-contractors better plan the amount of materials or labour needed, and may contribute to reducing wastes on the construction site.

CONSTRUCTION SITE SPACE-MONITORING MODULE

Storage spaces on a construction site can be categorised as – (1) exterior storage locations that refer to the areas surrounding the building under construction, and (2) interior storage locations within the building under construction. The primary role of a storage space is to house temporary storage facilities for materials and equipment. The material and equipment needs of a site changes as construction progresses and as a result so does the site layout. Temporary facilities, when not needed anymore, are dismantled so that the space can be used by other facilities. A temporary storage facility is a confined region on site, which is used to store a particular type of material or equipment. The amount of space allocated to each facility is defined at the site layout planning stage and depends on the quantity of material that will be stored in it. Each storage space has a maximum capacity above which it cannot accommodate more materials.

Delays in construction might lead to more materials being delivered to the site, than can be accommodated. This can be illustrated by the following example. Consider the activity of installing lighting fixtures on each floor. Each floor contains one hundred lighting fixtures, with twenty fixtures being installed on everyday. As a result each floor can be estimated to take one week to complete. The lighting fixtures are delivered to the site in batches of 240 fixtures, every 2 weeks to ensure a continuous supply of materials. The storage area is provided such that it can accommodate a maximum of 300 fixtures at a particular time. Now assume that 1 week into the activity, installation of light fixtures has to stop for one week because certain electrical lines have to be rewired. In this situation, it is likely that the second batch of light fixtures will arrive on site before the first batch is utilized. As a result the total number of fixtures on site will be 440, and hence cannot be accommodated by the storage facility. In this situation, space must be allocated to temporarily accommodate the excess materials. The materials should not interfere with any on-going activities, nor create a hindrance for storing other materials. It is also favourable to store them somewhere close to the original storage location, in order to minimize the transportation distance. We use the following 3-step methodology to monitor the available storage spaces on the construction site.

Step 1: Assessment of the storage capacity of the existing facility. The quantity of materials being used up can be obtained in the construction progress-reporting module. The quantity is then subtracted from the quantity of materials delivered to the site to obtain the quantity of material currently stored in the facility. This quantity is then subtracted from the maximum capacity of the storage facility to determine the feasibility of storage. If the materials cannot be accommodated in the temporary facility, they have to be assigned to other storage locations on the site. The following two steps deal with this.

Step 2: Assessment of the available exterior site spaces. Using the site layout plan we check the site for availability of storage spaces. In order to store the material delivery a storage space should meet the following two criteria – (1) it should be vacant during the time period for which the materials will be stored in it, and (2) it should contain sufficient space to accommodate the delivery. Every region on site, which satisfies this, is considered as a possible storage location.

Step 3: Assessment of interior storage spaces. In order to utilize the interior building spaces for material storage, it is important to identify the beginning date when any given floor becomes suitable for storing materials. In most building construction projects, this is given by the date of slab completion. Thus, we assign the start date of interior storage on a given floor as the date of slab completion.

The construction site space-monitoring module can hence tell us about the feasibility of material storage during different time intervals in the construction.

MATERIAL DELIVERY COORDINATION

Coordinating material deliveries is another important aspect of construction projects. As illustrated in figure 1, delays in construction activities might indirectly result in overcrowding of the site space. In our study we use two methods of mitigating excess inventory from accumulating on the site- (1) automated construction progress based pull ordering, and (2) supplier coordination module.

AUTOMATED CONSTRUCTION PROGRESS-BASED PULL ORDERING

The resource-loaded schedule tells us the quantity of materials that are consumed each day by construction activities. The rate of consumption, which forms the basis of inventory management, is then computed for each activity. When the quantity of materials in the inventory falls below a certain threshold, the system automatically registers a material order with the supplier. The date on which the automatic order is made depends on the lead-time and rate of consumption of that material. The order quantity depends on several factors such as the amount of storage space on site, the cost of ordering and the contractor's appetite for risk. The benefit of this system is that materials are automatically ordered when they get depleted. This is done by defining the reorder point, or the level of inventory that triggers a material order. The order quantity and re-order point are taken as inputs by the contractor. Each batch of materials that have been ordered is then given a unique reference number, for easy identification. Thus, the system will automatically create an order for a batch of materials, based on the progress of construction.

Delays in construction however, cause problems in storing materials on site, especially for longer lead-time materials. As explained in the previous section, delays in construction activities lead to excess materials being stored on site. If a material, which was ordered before the delay got reported, arrives on the site, it is likely that the site may not be able to accommodate it. This is because the site space allocated to this material is still occupied by the material for which there is a construction delay. This problem can be addressed in two ways – (1) postponing the delivery of affected materials, and (2) assigning a temporary storage area on or off-site. Postponing the delivery of subsequent materials requires coordination with suppliers, which is facilitated through the supplier coordination module.

SUPPLIER COORDINATION MODULE

Upon receiving a material order, the supplier coordination module is invoked. The main function of this module is to act as a bridge between construction activities on site and production activities at the supplier. A material order goes through various stages before it gets delivered to the site (see Figure 3**)**.

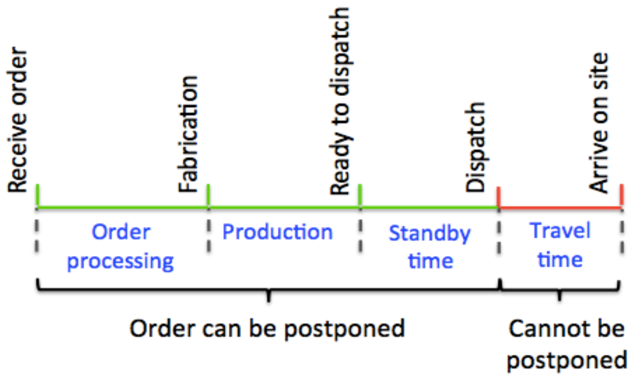

Figure 3: Stages a material order goes through before being delivered to the site

This information is necessary in determining which orders can and cannot be postponed. Postponing orders is vital for construction sites with limited site space, because it prevents crowding on site due to un-coordinated material deliveries. It is quite common for contractors to delay the deliveries of certain materials due to a hold up in construction activities on site. However, once a batch of materials has been dispatched from the supplier's factory or warehouse, it becomes expensive to postpone the order. In such situations, the contractor either arranges for an off-site temporary storage or buffer area, or allows the materials to be delivered to the site. The limitation of our system is that it currently does not consider the presence of such buffer zones. Our system requires the supplier to provide information about material orders on a regular basis in order to determine which orders can be postponed. A user interface will be provided to the supplier for updating the status of a material order. The supplier has to update the date when a material order is – (1) ready to dispatch, and (2) dispatched. Orders that cannot be delayed have to be assigned temporary storage locations either on or off the construction site. The material storage optimization module performs this assignment.

MATERIAL STORAGE OPTIMIZATION

Site layout planning should be carried out on two different levels – (1) tactical planning, which decides the storage location of each material, and (2) operational planning which ensures that the site layout plan is followed on a daily basis. In tactical planning the planned construction schedule is used to determine the material storage requirements and subsequently their storage locations. However, it is very rare for the construction to progress exactly according to schedule and as a result it may not be possible to follow the site layout. It is common practice for the site superintendent to make daily operational decisions regarding material storage that do not adhere to the original layout plan. This becomes problematic on confined construction sites, where site space comes at a premium and must be carefully allocated. In such projects, construction delays often render the site layout plan obsolete and the planning effort goes to waste. In this study we tackle site layout planning on an operational level and optimize material storage decisions in the context of schedule variations. Our system allocates materials in such a way that construction delays have a negligible impact on the site layout plan. This is performed through the following 3 steps:

Step 1: Calculate the amount of space required to accommodate the order. Check if materials arriving on site can be stored in their original storage locations. Yes, then assign them to be stored in original locations. If no, then go to step 2.

Step 2: From the construction site space-monitoring module, determine the possible locations on site where the order can be accommodated.

Step 3: Calculate transportation distance. Finally, the transportation distance is calculated between the new storage locations and the original storage location. This is necessary because the materials would have to eventually be shifted back to their original storage facility. The storage location with minimum transportation distance is assigned to the materials, in order to minimise the transportation effort.

DEMONSTRATIVE EXAMPLE

We tested the BIM-based SCM framework on an illustrative example of a building construction project. The project involves construction of an 8-story steel building with a glass curtain wall façade. Autodesk Revit was used to create the BIM model, which contained the material information of the building, and a site layout plan showing the temporary storage areas for materials was determined (see Figure 4).

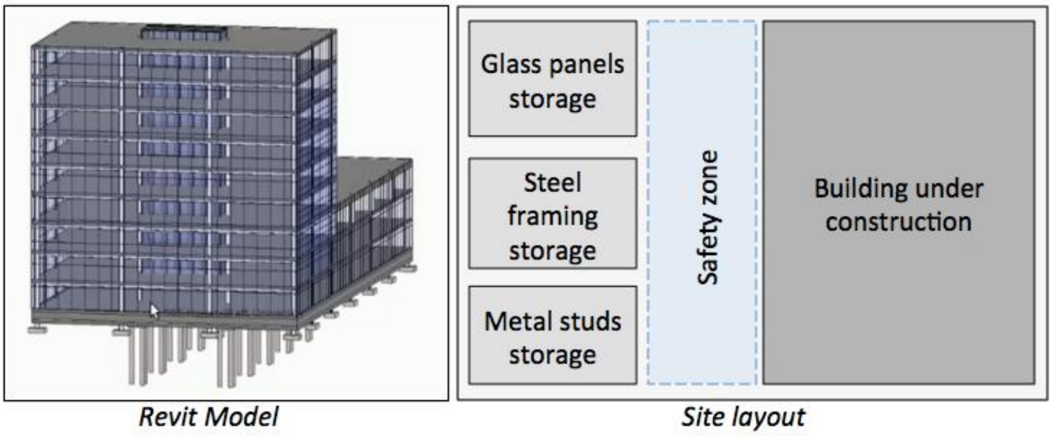

Figure 4: BIM model and site layout plan in the demonstrative example

Our framework is tested on the phase of construction dealing with installation of the glass curtain-wall façade. The major activities in this phase are – (1) installation of curtain wall stud layer, (2) installation of curtain wall framing, and (3) glass windows installations. Curtain-wall studs are first installed on each floor, which are immediately followed by erecting the steel frame. The glass panels are installed once the studs and framing have been completed. Each activity has a cycle time, i.e. the time necessary to complete the activity on one floor and move to the next floor, of 5 working days (1-week). The order quantity, reorder period, installation rate and lead-time of each material are shown in Table 1.

Table 1: Material order information

Activity	Material	Installation rate	Order quantity	Reorder point	Lead-time
Curtain-wall stud layer	Metal studs	200 units/day	800 units	300 units	1 day
Curtain-wall framing	Steel framing	100 units/day	400 units	250 units	2 days
Curtain-wall panels	Glass panels	50 units/day	200 units	175 units	3 days

Each one of these materials would have to be provided with a storage area on-site, which is based upon their maximum inventory level and the available site space. It is determined that the storage areas of the metal studs, steel framing and glass panels can accommodate a maximum of 1000, 500 and 250 units, respectively. Upon reaching the third floor, it is realised that the studs on the second floor were not installed according to specification. As a result, it is ordered that the second floor studs be completely removed and installed correctly, causing a delay of 1-week in the schedule. As a consequence the depending activities would also have to be stalled by 1-week. During this stage of construction the on-site inventory levels for each of the materials is as shown in Table 2.

Table 2: Material order and site inventory status

Material	On-site storage capacity	Current inventory amount	Quantity delivered in next order	Order status	Inventory after next delivery	Additional storage requirement
Metal studs	1000 units	200 units	800 units	Cannot be postponed	1000 units	None
Steel framing	500 units	200 units	400 units	Cannot be postponed	600 units	400 units
Glass panels	250 units	150 units	200 units	Cannot be postponed	350 units	200 units

Our system can foresee the material storage requirements of the project for the following weeks. It can be see that sufficient space to store the steel framing and glass panels would not be available, and as a result it would require material orders to be delayed. At this stage, the supplier coordination module is invoked to check the feasibility of postponing material orders. Since none of the orders could be postponed, the additional batches of materials would have to be accommodated in temporary storage locations on-site. The construction site space-monitoring module is then invoked to determine the feasible storage locations for the additional materials. Since the construction site does not have any additional on-site temporary storage locations, the materials delivered to the site would have to be stored within the built environment of the building. Thus, interior areas within the building can be planned in advance to accommodate the storage of additional materials.

CONCLUSIONS AND FUTURE WORK

Site layout planning has been well studied at a strategic and tactical level however, there is a lack of planning that goes into managing it on an operational level. In this study we presented a system framework for managing the material logistics and site layout for a construction site. The system leverages BIM technology to automate the creation of resource-loaded schedules, which are then used as a basis for planning the site layout and material logistics. Our system enables sub-contractor's to foresee the adverse effects of construction delays on the material logistics of a site and hence plan ahead of time to mitigate them. It also improves coordination between suppliers and contractors, by providing real-time updates about material order information. Using our system, contractors would be able to better gauge their daily usage of resources and would improve their planning and estimation. Future work will focus on extending the proposed framework to account for varying degrees of complexity in materials and site layout management.

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STABILIZING CRAFT LABOR WORKFLOW WITH INSTANTANEOUS PROGRESS REPORTING

Fernanda Cruz Rios[1], David Grau[2], Rizwan Assainar[3], Ram Ganapathy[4], and Jose Diosdado[5]

ABSTRACT

Stabilizing workflow is a common goal of research in lean construction, productivity, and production control methods. This study aimed to test the hypothesis that the combination of location-based work packaging and near real-time progress reporting contributes to reducing workflow variability. Some authors agree that daily monitoring allows timely actions to correct deviations from the baseline, which can increase workflow reliability. Thus, the objective of this study is to evaluate this statement in practice. The drywall installation in a healthcare facility served as the scenario for the test study. Drywall activities were divided into multiple tasks. Tasks were associated with locations and individually monitored. Although drywall tasks with unresolved constraints with mechanical activities did experience variations, a comprehensive analysis showed that most variations of workflow were proactively reduced.

KEYWORDS

Workflow, variability, lean, project controls, productivity, real-time.

INTRODUCTION

The production efficiency of the construction industry is fairly unsatisfactory, in spite of its relevant role in global and local markets. Lean construction has emerged as a possible solution for increasing the productivity and efficiency in the construction industry. An efficient management system is the key to achieving this goal. The lean

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production management aims to attack workflow variations, reduce waste, and increase the value of construction projects.

The results of the application of lean philosophy in the manufacturing industry are recognized. Unlike manufacturing, however, the construction environment carries several uncertainty factors. Each construction site has unique conditions and a number of variables such as weather, human resources, equipment, among others, bring uncertainty and unpredictability to the construction process. Controlling these variables can be extremely challenging, and such variability negatively affects productivity and leads to workflow variability and inefficiencies in production systems (Guo, 2002; Seppänen, 2009; Grau et al., 2014). Workflow variability, in turn, often produces a negative impact on cost, schedule, and/or quality (Hamzeh, 2009).

Stabilizing workflow (i.e. reducing workflow variations, increasing workflow reliability) has been a common goal in several past studies aiming to improve the theory and practice of lean construction. Authors have developed powerful frameworks and methodologies such as the Last Planner System, Location-Based Management System, and other location-based approaches to planning and construction (e.g. Ballard, 2000; Ballard and Howell, 2003; Seppänen, 2009; Seppänen, Ballard and Pesonen, 2010). The authors of these methodologies have been making additional suggestions to be tested on their implementation. Among the recommendations is the consistent collection and reporting of progress data and allowing timely alarms to correct deviations (Seppänen, 2009; Grau et al., 2014; Tang et al., 2014). However, there is not enough quantitative evidence that these strategies are successful to stabilize workflow.

This research builds on previous efforts and proposes to integrate a near real-time monitoring approach that allows a proactive progress assessment and timely corrective actions. Through the integration of small work packages and detailed monitoring, the proposed approach leads to a more instantaneous control of the work at the job site.

Indeed, this study has analysed the combination of location-based work packaging and near real-time progress reporting to reducing the workflow variability for drywall activities in a healthcare facility. The drywall packages were divided into work zones with daily supervision, which made possible to monitor the workflow in detail, and to allocate resources accordingly and provide corrective actions when necessary. Such approach allowed detailed productivity data to be collected on a daily basis and leaded to the results described in this paper.

BACKGROUND

Production management is at the essence of lean construction. A lean production management focus in work packaging and project controls is necessary to reduce and manage variability and uncertainty in the execution of planned tasks (Ballard et al., 2003). The primary strategy of lean construction is the look-ahead planning process. That is, the traditional critical path planning approach has been analysed and criticized by many authors, especially by lean thinkers (Ballard and Howell, 1994; Koskela and Howell, 2002; Hamzeh, 2009; Grau et al., 2014; Tang et al., 2014).

According to Koskela and Howell (2002), the lack of theory and understanding of concepts such as planning, execution, and controls lead to a counterproductive approach that undermines performance. Similarly, the traditional project planning is limited in what concerns scheduling. The traditional approach still makes use of the Critical Path Method (CPM). The CPM, however, fails to load resources in the contractor's schedule (Seppänen, 2009). Furthermore, CPM methods violate the principle of flow and lead to an increase of non-value adding activities (i.e. waste). As a response to these issues, Lauri Koskela introduced the theory of lean construction (Koskela, 1992). A core lean construction principle is to minimize variability (Ballard et al., 2005; Hamzeh, 2009).

Workflow variation can be thought as the variation of produced work at any moment in time, even though it is often simplified as the difference between the tasks that are predicted to be completed and the tasks actually completed (Liu, Ballard and Ibbs, 2011). Workflow varies if performance suffers from the impact of resources and constraints, that is, when it becomes unfeasible to predict the singular work that will be completed at any moment in time (Horman et al., 2004). This variation undermines project performance (Hamzeh, Ballard and Tommelein, 2012) and also has a negative impact on cost, schedule, and quality (Hamzeh, 2009). Liu, Ballard and Ibbs (2011) established a correlation between workflow variation and labour productivity. The authors analysed 134 weeks of production data on 10 working areas for a pipe installation project. The results showed a statistically significant correlation between productivity and workflow variation. Thus, reducing workflow variation can help improve labour productivity (Liu, Ballard and Ibbs, 2011). Other study achieved an improvement of 86% in productivity by improving workflow reliability (i.e. stabilizing workflow) (Ballard et al., 2003). Workflow reliability implies workload predictability. Without a predictable workload, capacity cannot be matched to load. Consequently, productivity deteriorates (Horman et al., 2004).

Production control can be defined as the monitoring of the performance of each execution against the plan, with corrective actions responding to possible deviations (Ballard and Howell, 1998). These corrective actions are the opposite as traditional results-oriented control methods. Results-oriented control is understood as the measurement of actual results and their comparison with the plan (desired results). Since this process intends to reveal problems after-the-fact, it is not efficient in timely identifying constraints and keeping the project on track (Ballard and Howell, 1994).

The Last Planner System (LPS) (Ballard 2000) emerged as a methodology to stabilize the workflow, increase planning reliability, and improve production performance (Hamzeh, Ballard and Tommelein, 2012). LPS tools are the look-ahead planning, commitment planning, and continuous improvement and learning (Ballard et al., 2003). In addition, LPS uses Percent Plan Complete (PPC) as a metric to track the work plan reliability. PPC equals to the number of completed tasks divided by the number of planned tasks for a given timeline. Ballard and Howell (1994) refer to an improvement in PPC as an indication of benefits from factors such as a more stable workflow. Indeed, LPS has a positive impact on workflow variation and labour productivity (Hamzeh, 2009).

One of the keys strategies of lean construction is small work packaging. It consists in dividing the work into small chunks of work in order to reduce constraints, such as work dependencies (Ballard et al., 2003). Ballard and Howell (1998) refer to work packaging as the link between scheduling and production control. In LPS, activities are broken down from phases to processes, then to operations or tasks, across the master schedule, phase schedule, look-ahead planning, and weekly work planning (Hamzeh, Ballard and Tommelein, 2012). The next level would be the daily task, or assignment, level (Ballard, 2000). These work assignments have to feasible, that is, their constraints must be timely identified and removed through look-ahead planning techniques.

Space conflicts in the job site can delay schedule and cause productivity losses (Guo, 2002). Location-based methods aim at reducing construction's complexity by planning production based on past production rates for similar projects (Seppänen, 2009). However, many researchers of such methods overemphasized theory and missed opportunities to implement the location-based concepts in production control. Seppänen (2009) proposed the Location-Based Management System (LBMS) as an attempt to fill this gap. Through an empirical study, he concluded that it is possible to use location-based management tools to improve the reliability and performance of a production system, for instance, by limiting dependencies and constraints based on location. As such, location-based planning can be observed as a complement to small work packaging.

LPS and LBMS are harmonizing production techniques. Seppänen, Ballard, and Pesonen (2010) raised the hypothesis that the combination of both approaches potentially reduces workflow uncertainty and increases productivity. LPS covers the human aspects of production, focusing on planning and commitment. LBMS is accountable for the technical aspects of controlling, and aims to streamlining workflow and reducing dependencies (Seppänen, Ballard and Pesonen, 2010). Ballard and Howell (2003) defended the importance of measuring the average duration of each task performed. Indeed, LBMS allows calculating such durations based on the quantities of material for each location, the labour consumption factor, and the crew size or equivalent work hours.

Although both LPS and LBMS have a firm theoretical foundation, various authors have already suggested necessary improvements and developments for a successful implementation. For example, Seppänen (2009) recommended generating timely warnings to allow the managers to respond to deviations with proactive actions. Seppänen also recommended to collect more consistent progress data in order to generate such timely alerts. Ballard et al. (2001) suggested "in-progress inspection" as a measure to reduce rework time and minimize waste. The proponents of LBS and LBMS have done several calls-to-action through their publications.

Measuring the productivity is essential to validate the quality of planned work (Ballard and Howell, 1994). The main contribution of this paper is the analysis of daily quantitative data to track the variation on produced work through a combination of geo-located work packages and real-time reporting mechanisms. The tested hypothesis is that such combination can contribute to stabilizing the workflow and improve the production control. The fundamental assumption is that a higher productivity variation (i.e. the difference between planned and actual productivity), exist when timely reporting mechanisms lack.

OBJECTIVES AND SCOPE

The objective of this study is to analyse the impact from the combination of geo-located and small work packages with a near-real time reporting capability on production workflow through immediate corrective actions. Thus, the hypothesis of this study is that small work packages provide an opportunity, as discussed above, to increase production, but also that a near-real time reporting or monitoring function is actually necessary to alert managers in a timely manner when deviations in the flow of work actually occur. This study adopted an Instantaneous Project Controls (IPC) approach to measure the difference between planned and actual field productivity in a near real-time manner. This project uses the drywall activity of a healthcare project located in Phoenix, AZ, as the test study.

METHODOLOGY

INSTANTANEOUS PROJECT CONTROLS APPROACH

The basis for the IPC approach is the relationship between construction quantities, labour resources, and tasks durations (Figure 1). The method starts with the extraction of construction quantities from as-designed data or models (e.g., Building Information Models). The production rate (quantity/time) for that particular task is then selected from a historical database of previously completed projects. These rates are useful to estimate the needed resources, such as crew, materials, and equipment properly. At the same time, the actual availability of resources is the basis to determine the task duration.

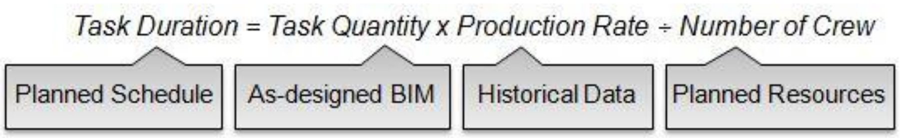

Figure 1: Relationship between quantities of construction, labour resources, and duration of tasks.

After estimating the amount of needed resources, the planners allocated them. This phase involves the subdivision of the facility’s work areas into work location packages through the combination of scheduling and the assignment of small work packages at each work zone. The ideal size of work package should reduce dependencies in order to allow a more continuous workflow. In this study, the authors designed work packages of about 200 man-hours size. Then, the tasks (i.e. the smallest evident entity of work) are assigned to each work zone.

The crew reports on a daily basis: 1) the Actual Start (AS) and Actual Finish (AF) dates for each location; 2) the man-hours and resources needed for each period of time and task, and 3) the actual quantities completed and the corresponding degree of completion for each task for the recorded time. Finally, the production manager adjusts resource allocation and works to solve constraints in order to correct deviations from planning. The daily monitoring allows the crew to make timely corrective actions to drive the productivity back to the planned values. The assumption is that, once the difference between actual and planned productivity reduces, the workflow variations also decreases. In summary, this process allows a constant flow of factual production rates in the job site, while the adjustment of resources allocation reduces the variation of productivity and hence workflow.

The data analysis and update of the historical database follows the completion of the construction phase. The database should guide decision-making in future projects (e.g. resource allocation, contractors’ selection), thus contributing to a continuous improvement of workflow stabilization methods. The envisioned controls and planning approach is summarized and illustrated in Figure 2.

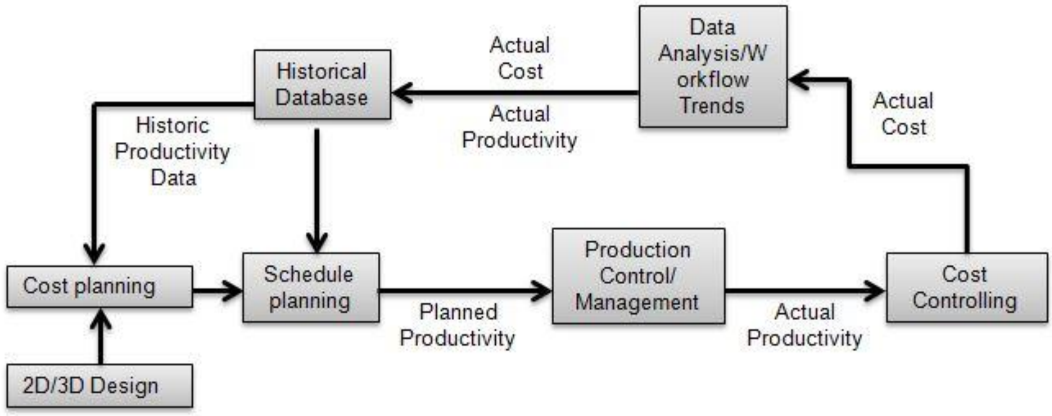

Figure 2: Instantaneous Controls and Planning Framework

DATA COLLECTION

The installation of 333 square meters of drywall in a hospital project supported this study. The total cost and duration for this particular activity were respectively $124,387 and 12 weeks. The contractor directly and continuously employed the drywall crews.

The contractor planned for 12 different drywall tasks: 1) Layout of walls, 2) Installing top track, 3) Framing full height wall, 4) Installing hollow metal frames, 5) Hanging drywall above ceiling, 6) Installing shaft wall, 7) Wall insulation, 8) Installing strap backing, 9) Hanging drywall below ceiling, 10) Framing of ceilings, 11) Framing of soffits, and 12) Hanging drywall at the ceiling level. The installation of mechanical, electrical, and piping (MEP) ducts was a constraint for the activities above the ceiling (framing of ceilings, soffits, and hanging of drywall at ceiling level). In addition, MEP activities were controlled by conventional Critical Path Methods (CPM) rather than through a lean planning approach.

A member of the contractor company spent 16 hours per week collecting productivity data. The contractor's foreman also invested work hours on reporting daily production log by work task and location. The BIM models were regularly updated according to the actual field production. The general contractor's project management database system (PMDS) provided data on production rates for drywall activity. This study collected drywall task data on schedule, planned production rates, resource crew allocation, cost estimates, and detailed actual field production data, such as: 1) planned start date, 2) planned end date, 3) planned total quantity, 4) planned duration, 5) planned man-hours, 6) actual quantity, 7) actual duration, and 8) actual man-hours.

ANALYSIS OF RESULTS

Each of the 12 different tasks related to drywall activity were analysed regarding planned and actual production data. This analysis has two stages. The first stage categorized the 12 observed tasks per the unit data (linear feet or square feet). An aggregate productivity analysis was performed for each task. The second stage analysed the 6 tasks with a minimum amount of data points (8 or more).

Individual Productivity Analysis

We performed an individual task productivity analysis for each task. Table 1 summarizes the planned and recorded production data of the 6 selected tasks in the drywall activity. The production data were used as a basis to compute the following:

Planned Production Rate. The planned productivity was computed by dividing planned total quantity by planned work-hours.

Actual Production Rate. The actual productivity per recorded field data was computed by dividing actual total quantity completed by actual work-hours consumed.

Mean Productivity differential. The actual productivity differential was computed as the difference between actual and planned productivity measures.

Table 1: Task Productivity Analysis

	Layout Walls	Frame Wall	Frame Ceilings	Frame Soffits
Unit	m/h	m/h	m^2/h	m^2/h
Planned Production Rate	8.37	1.29	1.84	0.28
Mean Productivity Differential	-1.79	1.28	-60	-0.12

The research team selected for individual analysis the six tasks with more collected data points. Through trend-timeline graphs, this study presents the productivity differential over a sequence of records. Productivity differential can be read as the variation of the productivity (i.e., the difference between actual and planned production rates).

The following graphs (Figures 3 and Figure 4) show an interesting production trend for each of the tasks in Table 1. In spite of the total productivity differential for each task, the trend after a reported deviation enabled to team to drive the production rates to the baseline or planned production rate. In the figures, the triangles represent the deviations. The horizontal line represents the baseline (planned) while the line represents the behavior of the productivity variation and changes. For example, analyzing the “hanging drywall below ceiling” task (Figure 4), the absolute value of productivity variation is significant, which means a considerable difference between actual and planned production rates. However, after each deviation was report, the line of actual production rate tends to approximate again to the baseline. Another result is that, for the tasks “framing ceilings” and “framing soffits”, most of the deviations were reported to be far below the planned. The reason for that is the existence of unresolved interdependencies with MEP tasks. Such positive trends are extensible to the analyzed 4 task below ceiling, while the trend of large deviations was observed for the two above-the ceiling analyzed tasks.

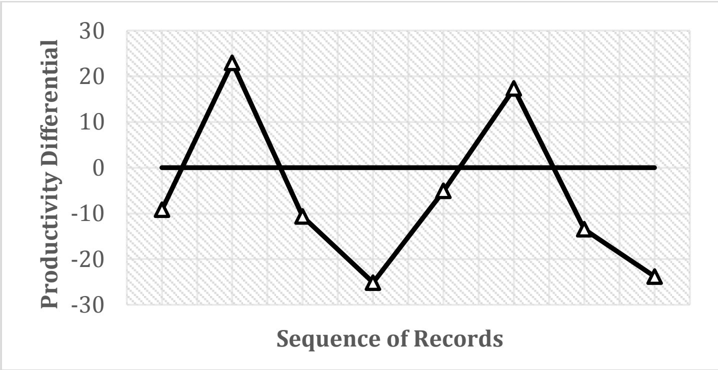

Figure 3: Productivity variation for Layout of Walls

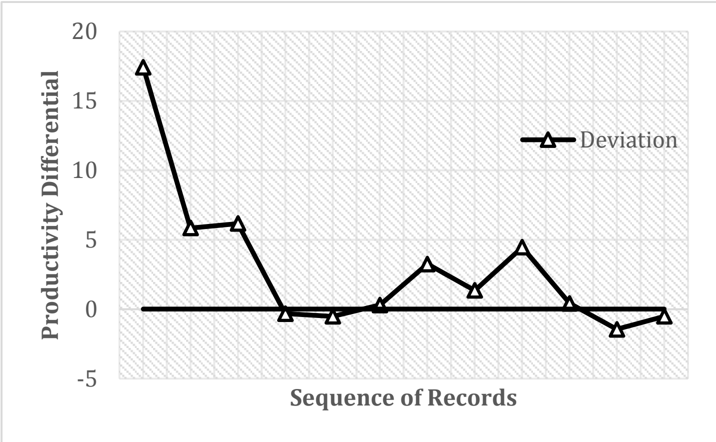

Figure 4. Productivity variation for Framing of Walls

Aggregate Productivity Analysis

The aggregate analysis assessed the mean productivity differential of the total group of tasks (i.e., 12 tasks previously mentioned). There are two different categories of tasks per unit quantity data, as shown in Table 1: linear (meter) and area (square meter). The authors decided to do a different aggregate analysis for each category due to the large difference between the mean range of planned production rates for area and length. The tasks measured in square feet were: 1) Hanging drywall above ceiling, 2) Wall insulation, and 3) Hanging of drywall below ceiling and hanging drywall at the ceiling. The tasks measured in linear feet were: 1) Laying out of walls, 2) Installation of top track, 3) Framing of walls, 4) Installation of shaft wall, 5) Installation of strap backing, 6) Framing of ceilings, and 7) Framing of soffits.

Overall, deviations actually fluctuated around the planned productivity (i.e. around a 0 deviation value) confirming the previous results for individual tasks. In other words, the deviations were frequent around the planned productivity and infrequent as those deviations were larger when compared to the planned productivity. In some cases the shape of such deviations resembled a normal distribution with the mean at the null deviation from the planned productivity. Such trend was also evident for both square and linear meters measured tasks.

Observations

The manual data collection technique used in this study was time-consuming. Indeed, the foremen showed a resistance to change to a proactive and semi-continuous data collection approach. To mitigate these issues, this research identified some opportunities for improvement of production control, such as the development of both an automated process and mobile applications to improve data collection techniques.

CONCLUSIONS AND FUTURE RESEARCH

This study investigated how the combination of geo-located work packages with daily progress reports can contribute to stabilizing workflow. Indeed, the proposal of small work packaging should always be accompanied by near real-time reporting functions. A continuous feed of data and read of information from the analyze data is necessary in order to provide an opportunity for the implementation of corrective actions. If not implemented, the benefits of small or geo-located work packaging approaches may not be fully realized. Importantly, the ability to monitor and correct production controls should also have an impact on the predictability of the planned work, so that both the planned work is supported by past performance data and the current production rates match the plan. Future research should expand the range of tested activities to a full project across trades, so that the results from this study can be further discussed.

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FORMWORK STANDARDIZATION AND PRODUCTION FLOW: LESSONS FROM AN AFFORDABLE HOUSING PROJECT IN ECUADOR

Eder H. Martinez[1], Ariana M. Alvear[2], Iris D. Tommelein[3] and Glenn Ballard [4]

ABSTRACT

Latin America and the Caribbean are experiencing a severe housing shortage. The construction industry plays a pivotal role in housing provision and must find means to increase output and productivity in housing construction. However, inefficient production techniques, commonly associated with the building industry, exacerbate the problem. Adopting standardization and industrialization practices is seen as an option in scaling up production. Nevertheless, the complex nature of the industry (e.g., the uniqueness of projects and uncertainty) poses challenges when implementing standardization approaches in housing construction. Particularly, formwork standardization requires advanced planning and coordination across project delivery stages. Such synchronization is fundamental to balancing the production flow and optimizing the standardization process. This paper presents the case study of VillaHermosa, an Ecuadorian affordable housing developer exploring formwork standardization in the construction of reinforced concrete housing units. The authors describe their standardization process, the challenges faced by the company, the results and the lessons learned from the experience, as well as a topic for future study.

KEYWORDS

Lean construction, formwork standardization, production flow, production balancing, affordable housing, collaborative design.

INTRODUCTION

Countries in Latin America and the Caribbean (LAC) are experiencing an affordable housing crisis. Currently, nearly 23% of urban residents in LAC live in slums, equivalent to 110 million people (United Nations, 2011). Governments are challenged

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to find means to increase the availability of housing (United Nations, 1965). As a result, the construction industry is a key stakeholder in addressing the problem. However, many issues in housing provision are attributable to inefficiencies in the building sector (Lizarralde and Root, 2008; Inter-American Development Bank, 2012), poor technology implementation in building processes (CEPAL, 1996, p. 180) and inadequate project delivery methods (UN-Habitat, 2003, p. 5). This, in addition to productivity issues commonly associated with construction activity (Allen, 1985; Sanvido, 1988; Arditi and Mochtar, 2000), only intensifies the problem.

The United Nations (1965) has long recommended standardizing and industrializing the industry in order to accelerate housing construction. Arguably, the nature of the building process (i.e., uniqueness, uncertainty, and complexity of production systems) prevents mechanization of work. Despite the singularities of the building process, the housing construction sector is well-suited for the application of standard work (United Nations, 1965; Inter-American Development Bank, 2012). Woetzel et al. (2014) estimated that by Lean approaches including standardization and industrialization, construction costs for affordable housing may be cut by 16%.

Standardization stands for the use of components, methods or processes enabling regularity and predictability (Gibb, 2001). In this area, formwork suppliers have made significant progress in bringing automation to concrete related operations through the use of standard modules that can be easily transported and assembled on site (Oberlender and Peurifoy, 2011). Nevertheless, several factors must be taken into consideration when applying standardization practices in housing construction, e.g., an overuse of standardization may lead to design conflicts (Gibb, 2001) and customer dissatisfaction (Dos Santos, et al., 2014). This notwithstanding, excessive use of unique components may increase a project's complexity, making it hard to manage (Tommelein, 2006). Therefore, a balance between customization and standardization must be struck. In addition, key decisions made at the design stage impact the construction process. The use of standard products requires a comprehensive evaluation of the production system since excessive standardization may affect flexibility at the production stage (Barlow and Ozaki, 2005; Jonsson and Rudberg, 2015). In particular, the use of standard formwork modules requires advanced planning and coordination in design and construction (Oberlender and Peurifoy, 2011). The link between product standardization and production process design must be analyzed in order to achieve a balanced production flow.

This paper examines the case study of VillaHermosa, an Ecuadorian affordable housing developer exploring the use of standard formwork for the construction of reinforced concrete houses. Based on observation, the authors describe the design process for standardization, the challenges faced by the company during this process, and the results of their experience. The paper ends with suggesting a topic for further research.

ABOUT VILLAHERMOSA

VillaHermosa is a developer based in Duran, Ecuador. The company is constructing an affordable housing project of over 10,000 single and multi-family units over the span of 8 years, starting in 2014. VillaHermosa is responsible for the design, procurement, and construction of the entire project, a position that provides it with broad control over the project delivery process. Because of its large size, the project is divided into 10 phases. This case study focuses on its first phase, which involves the design and construction of 700 single housing units to be completed by early 2017.

FORMWORK STANDARDIZATION

Standardization is the extensive use of components, methods or processes which enables regularity, repetition and a background of successful practices and predictability (Gibb, 2001). Component standardization specifically relates to the replacement of several components by a single one that can perform the functions of all of them (Perera, Nagarur and Tabucanon, 1999). Among other benefits, the use of standard products or components shortens lead times, improves quality and eases operations at the construction stage (Gibb and Isack, 2001; Pasquire and Gibb, 2002).

The performance of concrete activities generally plays an important role in the overall performance of projects that use structural concrete (Dadi, et al., 2012). Within concrete activities, formwork design has been noted as offering opportunities for standardization and industrialization (Shapira, 1999). The conventional and still widely-used system of timber and plywood formwork built on-site, has been set aside and replaced by more efficient modular systems. Formwork modular systems are fabricated in a shop and delivered to the construction site. On site, standard modules can be transported and assembled quickly. The use of standard formwork has several advantages (Oberlender and Peurifoy, 2011) over custom-built formwork:

- Simple installation that can be performed even by low-skilled workers
- Reduced erection time
- Higher number of reuses that leads to reduced overall costs of equipment
- Improved safety for the labor force
- Better quality concrete surfaces which reduces further finishing work
- Automation of formwork operations and improved productivity

Nevertheless, the implementation of standardization highlights the conflict between uniformity and variation. The tension between standardization and flexibility may result in design impotence (Gibb, 2001). In the context of housing design, the excessive use of standard products may cause customer dissatisfaction due to the variety of family profiles and the diversity of lifestyles in the population (Dos Santos, et al., 2014). In contrast, excessive customization may prolong the length of the construction process. The uniqueness of a facility may be valuable to the final customer, but using unique materials increases system complexity, making it more challenging to manage (Tommelein, 2006). As a result, developers must strike a balance between standardization vs. customization in order to handle production systems efficiently while still meeting customers’ needs.

In addition, the implementation of standard components must be evaluated beyond the design stage. It is recognized that the use of standard products must match the production system design (Jonsson and Rudberg, 2015) since the incorporation of standard products may harm the flexibility of the production process (Barlow and Ozaki, 2005). For this reason, the trade-off between productivity-related capabilities (e.g., cost and lead time) and flexibility (product and process) has to be carefully analyzed when designing the project’s production system (Nahmens and Bindroo, 2011). In terms of production system design, success in using modular formwork can be achieved only by proper planning at the architectural design stage and then requires advanced planning and coordination at the construction stage. Work sequence, reuse scheme, allocation of formwork sets, cranes and crews must be considered (Oberlender and Peurifoy, 2011). Consequently, it is crucial to evaluate the interface between the design of standard components and production capability in order to reach a balanced production flow.

CASE STUDY AT VILLA HERMOSA

FIRST RUN STUDY

Based on local market studies, VillaHermosa decided to design 20 preliminary house models, the smallest one being a 40 m^2 1-bedroom and the largest one being an 80 m^2 4-bedroom. As a first run study, the company built four demonstration houses. The purpose of this study was to assess the units' constructability and to evaluate construction performance in terms of time and budget. After this experience, the team identified several constructability issues related to variation among unit models. For instance, the different dimensions of concrete elements impeded the reutilization of formwork panels. The additional work required to adapt panels to different concrete elements' dimensions resulted in a significant waste of resources. Moreover, the construction team noticed formwork activities demanded a significant amount of time and resources. After this experience, the company reevaluated the house designs and decided to standardize the dimensions of concrete elements like rooms, walls, window- and door openings, and stairs.

DISCUSSION OF STANDARDIZATION VERSUS CUSTOMIZATION

As described, excessive use of standardization may lead to customer dissatisfaction. In the case study, the level of standardization vs. customization in the models became an important topic of discussion for VillaHermosa's project team members. On one hand, the sales team wanted to maximize customization. More variation in housing models facilitates sales since it is easier for sales agents to find a model that meets specific customers' needs. On the other hand, the construction team wanted to moderate variation. As experienced during the first run study, more variation considerably increased the complexity of operations on site.

After several iterations, VillaHermosa decided to keep 12 base models. However, in order to offer more customization, they decided to include certain architectural "add-on" elements to satisfy a broader range of customers. By adding iconic elements to the 12 base models (i.e., balconies or different types of finishes), the design team was able to find a balance between standardization and customization. As a result, the 12 base models became 47 types of houses.

FORMWORK SUPPLIER SELECTION

The team put special care into the selection of the formwork supplier. During this process, a bidder's technical expertise and willingness to participate in a collaborative design process was of great importance in awarding the contract. Finally, VillaHermosa selected a formwork provider with more than 50 years of experience in the market. This supplier would engineer and manufacture concrete forming systems according to VillaHermosa's specific requirements.

FORMWORK STANDARDIZATION PROCESS

VillaHermosa's goal was to come up with a project that offered options for different customers' profiles. The company also aimed to design a project that reduced variation, optimized concrete related operations and eased production flow. With this purpose, stakeholders' interests were aligned in order to balance standardization vs. customization. Team members involved in the collaborative design process stacked two types of pre-existing designs up against each other. On one side were the preliminary designs of housing units made by VillaHermosa's architectural team. On the other side were the standard panels marketed by the formwork supplier. In order to optimize formwork standardization, the existing models were adapted to the dimensions of standard panels. In doing so, VillaHermosa and the formwork provider set the following goals:

- Reduce the number of formwork equipment on site – Reduce inventory
- Standardize housing models for concrete operations – Reduce variation
- Develop one LEGO set capable of building all models – Interchangeability

Figure 1 shows how the design process proceeded for each group of housing models. Models were standardized in batches. The cycle depicted in figure 1 repeats itself several times after all the shells of houses were completed. The design process lasted four months. At this point two sets were used, each one flexible enough to build any of the twelve base models.

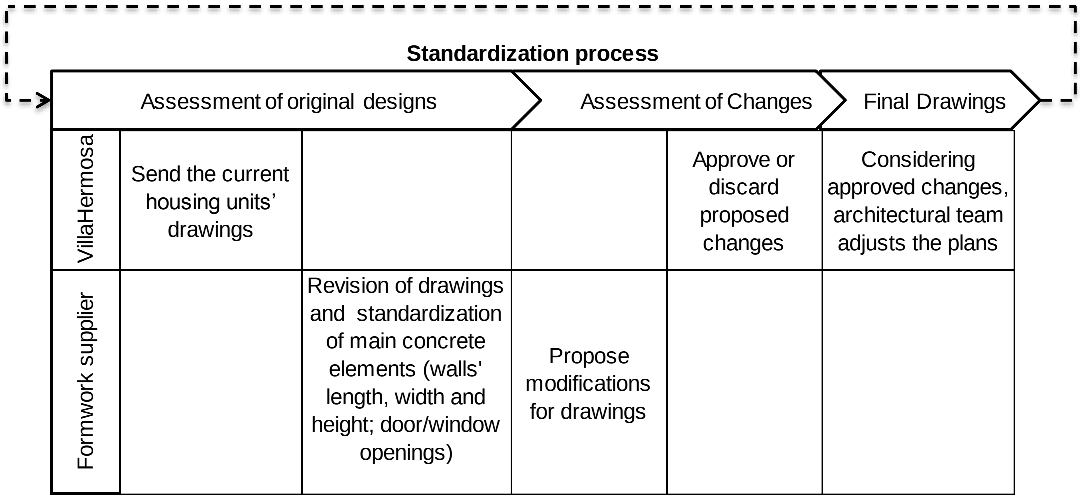

Figure 1: Standardization process at VillaHermosa

BALANCING PRODUCTION THROUGH DESIGN

Success in using standard formwork depends on proper design as well as adequate correlation with construction processes. In alignment with this statement, and considering the use of two flexible formwork sets, VillaHermosa and the formwork provider simulated construction operations. Their objective was to optimize the use of each formwork set in order to achieve a balanced production rate that met sales.

In order to meet demand, the construction team had to produce 2 houses/day. This meant having two construction crews working simultaneously, each one capable of building any model. However, the size of the models and the setup of project lots affected the production flow. During the simulation, the team identified challenges and collaboratively implemented the following solutions.

Problem 1: Idle Inventory: The initial production process design considered using two formwork sets, each one capable of building any base model. This solution was flexible since two crews working simultaneously could build any type of house. However, a typical block design has two lot sizes, one 67 m^2 and one 100 m^2 respectively with an average distribution of 30% and 70% per block. As shown in figure 2, for each lot, only certain kinds of house models are allowed to be built. The 67 m^2 lot allows for the construction of small models while the 100 m^2 lot allows for the construction of big models. Since the project had small and big models, several inventory pieces (approximately 45%) would remain unused when building small models.

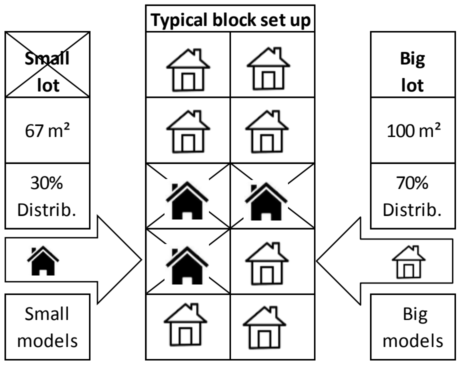

Figure 2: Typical block setup and its corresponding house model

Solution 1: In collaboration with the formwork supplier, VillaHermosa readapted the set's configurations so as to have one set for small models and one for big models, thereby reducing the idle inventory considerably during the construction process.

Problem 2: Unbalanced Production per Delivery Zones: Given one formwork set for each type of house, two specialized crews are necessary to maximize inventory use and make production efficient.

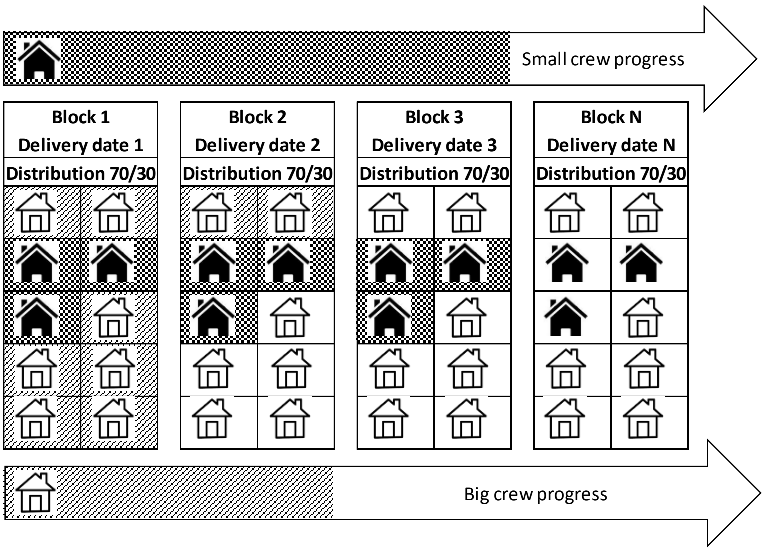

Figure 3: Unbalanced production flow through delivery blocks

Nevertheless, the specific distribution of different-sized lots (30/70) and the due dates for the completion of blocks imposed new challenges. Using two specialized crews with the 30/70 lot distribution resulted in an unbalanced production flow of small and big houses. By sharing only 30% of the work per block, the crew working on small models would work faster than the crew working on the big models. Schematically, figure 3 shows construction progress at day 9. If each crew built 1 house/day, at day 9, the crew for small models would be working on block 3. However, block 2 would still be under construction because the big models would not be completed yet. Although the production rate would still meet the demand of 2 houses/day, the production flow per delivery zone would not be met. This was a relevant issue since VillaHermosa is committed to delivering the project by block at specific dates.

Solution 2: In order to balance the production per block, the team included a specific house model in the design that could be built on either the 67 m^2 or 100 m^2 lot. This model can be used as a "wildcard" to achieve a balanced 50/50 distribution of small and big models per block. By adding a subtle design variation that indeed reduced the level of standardization in the original design, flexibility was obtained at the production level, enabling an even progression in the production flow.

Problem 3: Sales Point Coordination: By implementing this design change, the team set a balanced production system. However, the balanced distribution was based upon sales to customers since the sales representatives had to ensure that the wildcard house model was being sold in every block to keep the 50/50 distribution. Consequently, the project would require control over the sales per block or loose the balance in the production process.

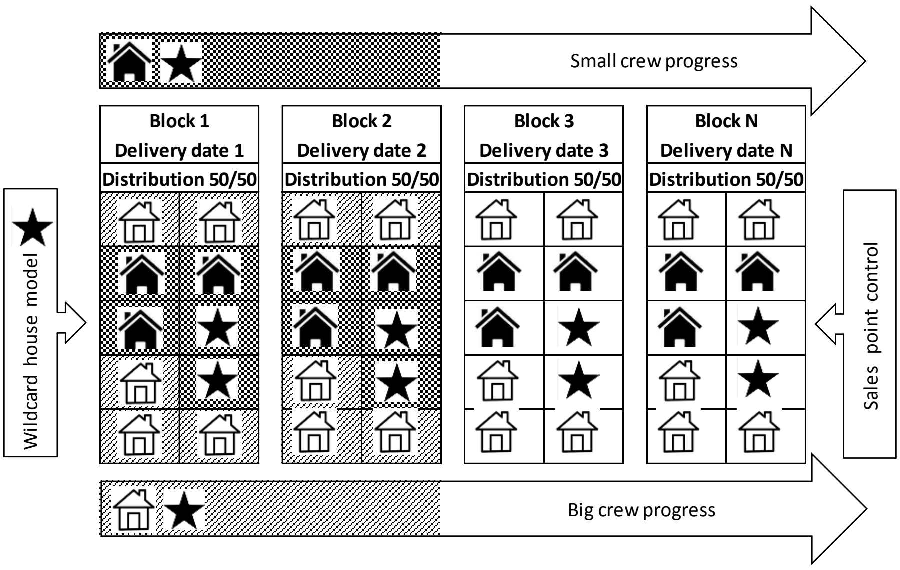

Figure 4: Balanced production flow through delivery blocks resulting from the wildcard house model and sales point control

Solution 3: In order to achieve control over the sales per block, VillaHermosa's sales software set a counting system that calculates the percentage distribution for the different house models. Once the sale of big houses per block reaches over 50%, a restriction is set to only allow the sale of the wildcard house in the big lots. Thus far, this had not been a problem since the wildcard model has sold well, thereby allowing an equal distribution between crews without limitations to the sales representatives. Figure 4 schematically represents this new balanced production, which takes into account the wildcard house model and the sales point control.

RESULTS

In the first design iteration, the team standardized the houses' concrete elements in order to have only two formwork sets capable of building any of the twelve models. However, this left 45% of formwork equipment idle when building small models. In response, the team designed two specialized sets, one for the small models and one for the big models. This alternative was efficient in terms of inventory use but inadequate when considering the balance of the production flow.

In a second design iteration, the team decided to include variation through a wildcard model that can be built with any formwork set. This design variation helped the team achieve a balanced flow of production between construction crews and allowed the team to meet project delivery dates per block. The team at this point realized that the balance in the production process could be achieved only at the sales point (Wardell, 2003) and to that effect set a subtle restriction at the sales point.

Through collaborative design and coordination among team members, the standardization process benefited the project. Table 1 shows the original setup cost $631,184. After completing the design iterations, the final setup cost $501,597. The final setup also reduced inventory by 25%, which eased operations on site.

Table 1: Final result of design standardization process

Item	Original setup	Final setup	Reduction [%]
Number of pieces	3,360	2,492	-25.8
SKUs/Items	944	687	-27.2
Total Cost USD	631,184	501,597	-20.5

CONCLUSIONS

This case study describes a successful experience of formwork standardization in an affordable housing project in Ecuador. In the first stage, the formwork standardization process focused on design, aimed to reduce variation and facilitate construction operations. However, the design team realized that further involvement of other project stakeholders was needed to optimize standardization. The success of this experience relied on collaboration among project members, as well as planning and synchronization among different project delivery stages.

Key decisions made early in design were crucial to making the final solution efficient overall. The production process simulation performed by the team identified the imbalanced production flow resulting from the original design. To overcome this imbalance, the company's construction and sales teams helped find the solution. This case study demonstrated the link between design and production. Specifically, the use of standard components affected the flexibility in construction and production flow balance. Incorporation of the wildcard model added variation and reduced standardization, yet proved to be beneficial by helping the team achieve a balanced production flow. This improvement, in addition to modifications of sales procedures, facilitated the application of a solution that optimized the whole, not parts, of the production system.

The involvement of an experienced formwork supplier had a significant impact on this success. Nevertheless, professionals participating in this project agreed that involving the formwork provider earlier in the design process could have helped the team avoid initial design iteration, leading to the development of an even more efficient final solution. A barrier impeding the application of this improvement was the competitive bidding process required by the company in awarding contracts.

An aspect relevant for discussion relates to the type and scale of the project and its relation to standardization practices. In order to maximize affordability, developers in the affordable housing industry accept small profits per housing unit so they will aim to maximize the benefits of economies of scale. In this context, the standardization of building components becomes crucial for the success of projects. Specifically in this case study, small profit margins achieved in the production of a single housing unit can be replicated in the following units, maximizing overall gains.

This case study focused only on the benefits of standardization in the design process and its correlation with production flow. However, standardization also has an impact on labor training and productivity, especially when dealing with repetitive work. This important topic is driving future research at VillaHermosa.

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INTEGRATING TASK FRAGMENTATION AND EARNED VALUE METHOD INTO THE LAST PLANNER SYSTEM USING SPREADSHEETS

José L. Ponz-Tienda [1], Eugenio Pellicer [2], Luis F. Alarcón[3], and Juan S. Rojas-Quintero[4]

ABSTRACT

Construction schedulers make use of several tools as project management software of general purpose and spreadsheets for applying the Last Planner System of Production Control. This widespread practice has the disadvantage of working with questionable algorithms and models difficult to adapt to the construction industry, besides having to work with disconnected and complex information to manage data. In this paper a new layout and computation of multidimensional non-cyclic directed graphs based on its adjacency matrices is presented. All the precedence relationships are considered, in addition to the optimal and discretionary fragmentation of task in real conditions with work and feeding restrictions. This approach has been implemented with Visual Basic for Excel. A new approach for the representation and computation of projects for the Last Planner System of Production Control is presented. This approach is integrated with the management of the Earned Value and ad-hoc complex optimization. LPS^{TM}, CPM, EVM and PPC are found to be complementary, and the Zaderenko´s algorithm modified and implemented in Excel can be used to integrate them.

KEYWORDS

Lean construction, Last Planner System, Construction Scheduling with spreadsheets.

INTRODUCTION

To improve the efficiency of the planning process of construction projects, practitioners schedule through a hierarchy of three levels from low to high level of detail. Ballard and Howell (1998) propose The Last Planner System of Production

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Control (LPS™) as a hierarchy of three levels from low to high level of detail: master plan and phase planning (long term), look-ahead planning (medium term), and commitment planning (short term). The long term planning is to obtain a general plan establishing the strategic targets (phase planning) aimed to developing more detailed work plans and identify all the work packages for the construction project, showing the main activities, their duration and sequences indexed at the top level of the work breakdown structure (WBS henceforth). In the middle term planning, the schedulers develop actions in the present to produce a desired future, preparing, analysing, and solving the conflicts and restrictions in a lower and more detailed level of the WBS. In the short term planning or Weekly Work Planning (WWP), collaborative agreement or commitment planning works at the lowest levels of the WBS making things happen, bearing in mind the work that is being done now and that is made-ready to be done (Koskela, Stratton and Koskenvesa, 2010).

Lean construction practitioners make use of custom spreadsheets and project management software of general purpose, which implements a group of mathematical algorithms known in a generic form as Critical Path Method (CPM henceforth). These tools are fluently used by practitioners and implemented in the commercial software designed to assist them in the scheduling process. However, many times practitioners are not aware of the implications about using these algorithms or they do not understand CPM software properly. Furthermore, even skilled technicians may have problems interpreting the implementing criteria of CPM algorithms as well as its relaxations (Wiest, 1981), not properly documented in the management commercial packages even those of the highest quality. In addition, the results obtained on the benchmarking tests indicates that not only they are hardly applicable or feasible in realistic environments, but that they are not currently competitive with the best state-of-the-art algorithms available in the literature (Mellentien and Trautmann, 2001; Trautman and Baumnn, 2009). This widespread practice has the disadvantage of working with questionable obsolete algorithms and models difficult to adapt to the construction industry, besides having to work with disconnected and complex information to manage data.

CPM has been widely criticized as inadequate to the task of controlling work in projects (Koskela, et al., 2014), and Earned Value Management (EVM) for managing task at the operational level, suggesting that LPSTM and Percentage of Promises Completed (PPC) are more appropriate to manage works when it is applied to the operation level (Kim and Ballard, 2010). LPSTM is a collaborative, commitment-based planning system, and CPM is a class of operations research algorithms for computing the times of the activities based on its precedence restrictions. PPC is the measure of promises completed on time and EVM is a tool for production control by a comparison between budgeted and scheduled with performed, obtaining different measures to report the progress of the project in terms of cost, production and time (Ponz-Tienda, Pellicer and Yepes, 2012). LPSTM, CPM, EVM and PPC are complementary rather than competitive, and the inadequacy is on the fitness of the implemented algorithms to the construction industry. Research is heading towards the establishment of alternative project control accounting systems not subject to the traditional limitations of EVM, such as unbalanced process flows and lack of predictability (Kim and Ballard, 2000), mainly in terms of workflow and value generation (Kim, Kim and Cho, 2015)

In this paper a new layout and computation of multidimensional non-cyclic directed graphs based on its adjacency matrices is presented with a realistic approach in construction production planning. All the precedence relationships are considered, in addition to the optimal and discretionary fragmentation of task in real conditions with time, work and feeding restrictions. This approach has been implemented with Visual Basic for Excel in a complete and adaptable application for the LPSTM integrated with the management of the EVM and ad-hoc complex optimization models.

The reminder of this paper is structured as follows: Section 2 provides a literature review of the Project Scheduling Problem with GPRs and feeding precedence relationships. Section 3 details the proposed algorithms for multidimensional non-cyclic directed graphs based on its adjacency matrices. In section 4, the proposal implemented for spreadsheets is shown. Finally, conclusions are drawn.

LITERATURE REVIEW

Projects are usually represented as acyclic directed graph without cycles and circuits in two ways, considering the activities on the arrows of the graphs know as *Activity-on-Arrow* (*AoA*) (Kelley and Walker, 1959; Malcolm, et al., 1959), and considering the activities on the nodes of the graph, know as *Activity-on-Node* (*AoN*). The *AoN* model was introduced by Roy (1962 cited in Kerbosch and Schell, 1975) and later improved with the well-known Precedence Diagramming Method (*PDM*) (IBM, 1968).

The *PDM* graphs considered the activities as non-splitting allowed and contemplated four kinds of *Generalized Precedence Relationships* (*GPRs*): *finish-to-start* ($FS(z_{ij})$), *start-to-start* ($SS(z_{ij})$), *finish-to-finish* ($FF(z_{ij})$) and *start-to-finish* ($SF(z_{ij})$). The *PDM* graphs with *GPRs* present an anomalous effect, called *reverse criticality*, that grates against one´s natural feelings about the consequences of lengthening or shortening a job (Wiest, 1981), changing the concept of a critical path itself. Crandall (1973) proposed the first splitting allowed algorithm that partially avoids the reverse criticality. This algorithm considers that "*disallowing the splitting of activities was an excessive relaxation of the real problem"*, presenting a heuristic algorithm to compute the times and the minimum duration of the project.

The Crandall´s algorithm was improved by Moder, Philips and Davis (1983), including the start-to-finish relationship. More recently, Valls, Martí and Lino (1996) analyse the Crandall's algorithm, proposing a new computation and more realistic treatment of the *start-to-finish* relationship. Other relaxed algorithm have been proposed by Hajdu (1996), but it provides infeasible solutions to the problem in some cases.

An important and not well-known feature of graphs, especially project graphs, is that they can be represented by indexed matrices, based on its precedence relationships and represented by adjacency matrices. This characteristic is regardless of its nature, no matter if it is an *AoA* graph or an *AoN* graph.

The first algorithm to compute the times of the activities of a project based on its matrix representation was proposed by Zaderenko (1968). The Zaderenko´s algorithm only considered the *finish-to-start* relationships, computing the early start and finish of the activities. The Zaderenko´s proposal was improved by Ponz-Tienda (2011), proposing a new representation and computation of multidimensional non-cyclic directed graphs based on its adjacency matrices considering all the *GPRs* for the non-splitting allowed case and feeding precedence relationships.

INDEXING CRITERIA WITH SPREADSHEETS

The indexing criterion is based on the Zaderenko´s proposal, in which each $a_{j,j}$ element of the adjacency matrix correspond to the lead/lag of the relationship between an activity *j* and its predecessor ones (*i*) (*Figure*).

			Predecesor activities					
		duration	1	2	...	i	...	n
Activities	1	d_1	$a_{1,1}$	$a_{1,2}$	$a_{1,...}$	$a_{1,i}$	$a_{1,...}$	$a_{1,n}$
	2	d_2	$a_{2,1}$	$a_{2,2}$	$a_{2,...}$	$a_{2,i}$	$a_{2,...}$	$a_{2,n}$
	...	$d_{...}$	$a_{...,1}$	$a_{...,2}$	$a_{...,...}$	$a_{...,i}$	$a_{...,...}$	$a_{...,n}$
	j	d_j	$a_{j,1}$	$a_{j,2}$	$a_{j,...}$	$a_{j,i}$	$a_{j,...}$	$a_{j,n}$
	...	$d_{...}$	$a_{...,1}$	$a_{...,2}$	$a_{...,...}$	$a_{...,i}$	$a_{...,...}$	$a_{...,n}$
	n	d_n	$a_{n,1}$	$a_{n,2}$	$a_{n,...}$	$a_{n,i}$	$a_{n,...}$	$a_{n,n}$

Figure 1: Indexing criterion of the adjacency matrix

If the activities of the project are ordered in a topological way, then $\forall i \leq j \;\Rightarrow\; a_{ij} = NULL$, obtaining the simplified matrix shown in *Figure* .

			Predecesor activities					
		duration	1	2	...	i	...	n
Activities	1	d_1						
	2	d_2	$a_{2,1}$					
	...	$d_{...}$	$a_{...,1}$	$a_{...,2}$				
	j	d_j	$a_{j,1}$	$a_{j,2}$	$a_{j,...}$			
	...	$d_{...}$	$a_{...,1}$	$a_{...,2}$	$a_{...,...}$	$a_{...,i}$		
	n	d_n	$a_{n,1}$	$a_{n,2}$	$a_{n,...}$	$a_{n,i}$	$a_{n,...}$	

Figure 2: Simplified adjacency matrix

And the algorithm for computing the times of the activities is shown in pseudo-code 1:

Table 1: Pseudo-code 1 Conceptual algorithm

Forward Pass	**Backward Pass**
FOR $(j=1,n,+1)$	**FOR** $(i=n,1,-1)$
FOR $(i=1,j-1,+1)$	$LF_i = makespan$
IF $a(i,j) \neq NULL$ **THEN**	**FOR** $(j=i+1,n,+1)$
$ES_j = \max(SS_j, EF_i + a(i,j))$	**IF** $a(i,j) \neq NULL$ **THEN**
ENDIF	$LF_i = \min(LF_i, LS_j - a(i,j))$
$EF_j = ES_j + d_j$	**ENDIF**
$makespan = \max(makespan, EF_j)$	$LS_i = LF_i + d_i$

The previous algorithm can be improved including all the *GPRs* precedence relationships applying a multidimensional adjacency matrix with two rows and columns for each activity (Figure).

Furthermore, can be included the different nature of relationships as work and feeding precedence relationships applying equation 1, and the discretional fragmentation of activities applying the criterion exposed in Figure and equation 2.

$$\forall a_{ij} = z \mid z \neq NULL \Rightarrow \begin{cases} 0 \le z < 1 & a_{ij} \text{ is a feeding relationship} \\ |z| \ge 1 & a_{ij} \text{ is a work relationship} \end{cases} \quad (1)$$

				Columns	
				2·i-1	*2·i*
				Activity i	
				Start	*Finish*
Rows	*2·j-1*	*Activity j*	*Start*	$a_{2\cdot j-1,2\cdot i-1}$	$a_{2\cdot j-1,2\cdot i}$
	2·j		*Finish*	$a_{2\cdot j,2\cdot i-1}$	$a_{2\cdot j,2\cdot i}$

Figure 3: Multidimensional adjacency matrix

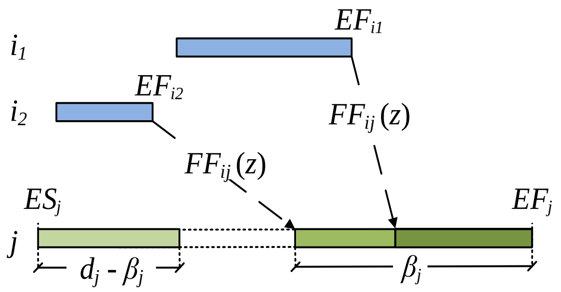


Figure 4: Splitting criterion of activities

$$\beta_j = \max\left(FF(z_{ij}),\ SF(z_{ij}) \right),\ \forall i \text{ predecessor of } j \quad (2)$$

And the algorithm for computing the times of the activities with feeding/work *GPRs* is shown in Table 2*: Pseudo-code 2* and Table 3*: Pseudo-code 3*:

Table 2: Pseudo-code 2 Forward pass algorithm with feeding/work GPRs

$\textbf{FOR}\ (j = 1, n, +1)$

$ES_j = SS_j;$

$\textbf{FOR}\ (i = 1, j-1, +1)$

$SSLag_{ij} = a(2\cdot j-1,\ 2\cdot i-1): \textbf{IF}\ SSLag_{ij} < 1\ \textbf{THEN}\ SSLag_{ij} = SSLag_{ij}\cdot d_i;$

$FSLag_{ij} = a(2\cdot j-1,\ 2\cdot i);$

$SFLag_{ij} = a(2\cdot j,\ 2\cdot i-1): \textbf{IF}\ SFLag_{ij} < 1\ \textbf{THEN}\ SFLag_{ij} = SFLag_{ij}\cdot d_i;$

$FFLag_{ij} = a(2\cdot j,\ 2\cdot i): \textbf{IF}\ FFLag_{ij} < 1\ \textbf{THEN}\ FFLag_{ij} = FFLag_{ij}\cdot d_j;$

$\beta_j = \max(\beta_j, FFlag_{ij}, SFlag_{ij});$

$SSlag_{ij}\left[\begin{array}{l}\textbf{IF}\ \beta_j - d_j < SSlag_{ij}\ \textbf{THEN}\ k_{ij} = EF_i - d_i + SSlag_{ij} - ES_i\ \textbf{ELSE}\ k_{ij} = SSlag_{ij} \\ ES_j = \max(ES_j, ES_i + k_{ij});\end{array}\right.$

$FSlag_{ij}\left[ES_j = \max(ES_j, EF_i + FSlag_{ij}):\right.$

$FFlag_{ij}\left[EF_j = \max(EF_j, EF_i + FFlag_{ij});\right.$

$SFlag_{ij}\left[\begin{array}{l}\textbf{IF}\ \beta_j - d_j < SFlag_{ij}\ \textbf{THEN}\ k_{ij} = EF_i - d_i + SFlag_{ij} - ES_i\ \textbf{ELSE}\ k_{ij} = SFlag_{ij} \\ EF_j = \max(EF_j, ES_i + k_{ij});\end{array}\right.$

$EF_j = \max(EF_j, ES_j + d_j);$

$\textbf{IF}\ j\ \textit{is not fragmentable}\ \textbf{THEN}\ ES_j = EF_j - d_j;$

Table 3: Pseudo-code 3 Backward pass algorithm with feeding/work GPRs

FOR $(i = n, 1, -1)$

  FOR $(j = i+1, n, +1)$

    $LS_i = \min i\left(LS_i, LS_j - k_{ij}\right) : LF_i = \min\left(LF_i, LS_j - FSlag_{ij}\right);$

    $LF_i = \min\left(LF_i, LF_j - FFlag_{ij}\right) : LS_i = \min\left(LS_i, LF_i - d_i\right);$

    IF *i is not fragmentable* **THEN** $LF_i = LS_i + d_i;$

IMPLEMENTATION IN AN HOLISTIC PULL SYSTEM

The previously exposed algorithms have been implemented in an Excel add-in that can be downloaded from http://goo.gl/a7G3L3 (Figure). This app includes the matrix algorithm exposed in pseudo-code 1 called *Matrix Pro*, the pseudo-code 2 and pseudo-code 3 for multidimensional adjacency matrices for *GPRs* called *Matrix GPRs*, and a suite of utilities for managing called *Matrix Commitments*.

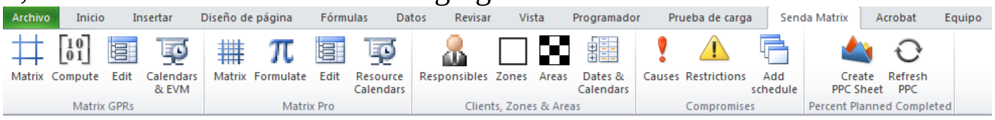


Figure 5: Senda Matrix Ribbon for Excel

The software completely supports the pull system of the LPS™, including location and responsibilities definition, making use of Excel's features, especially the unlimited possibilities of exchange of information between books and sheets (Figure 6).

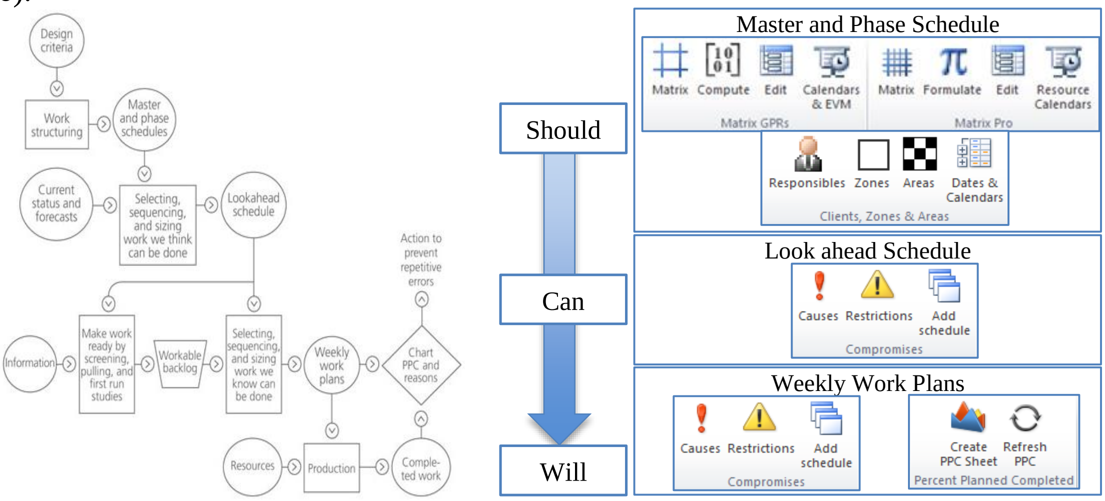


Figure 6: LPS™ (Ballard, 2000) Pull System with Senda Matrix

For a better understanding of the pull process with *Senda Matrix*, a practical example of application that supports the *LPS™* has been included. The example of application is the construction of a five floors building for classrooms and offices.

MASTER AND PHASE SCHEDULE

The main program has been scheduled with *Matrix GPRs* and contemplates seventeen activities (Figure 7), each one with different continuity conditions and feeding and work precedence relationships.

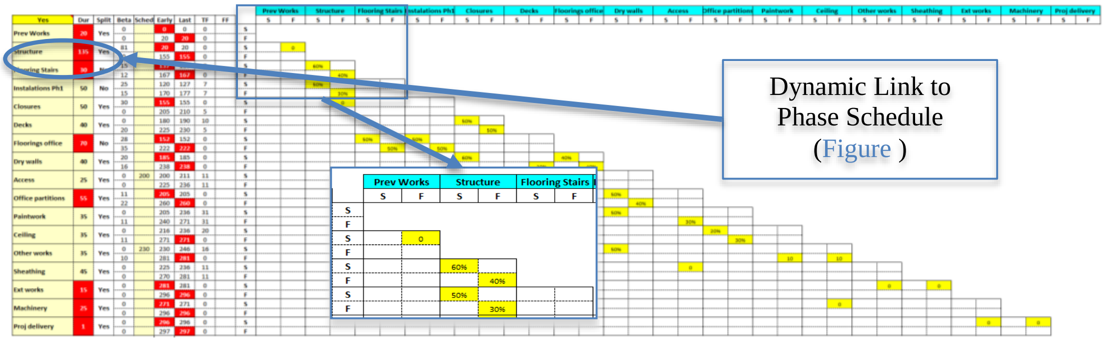
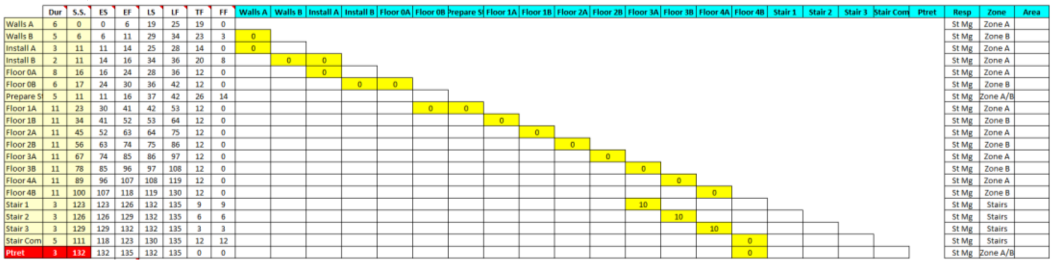


Figure 7: Main Program representation with Matrix GPRs

The Structure activity of the Main Program was analysed in depth with twenty detailed activities, as a Phase Schedule. The structure phase was scheduled using *Matrix Pro* (Figure) in a different book, applying a dynamic link from the main program. A RCPSP (Resource Constrained Project Scheduling Problem) optimization model was applied considering an availability of five workers. An optimal makespan for the structure of 135 days was obtained against the initial makespan of 166 days (Figure) (Ponz-Tienda, 2011; Ponz-Tienda, Pellicer and Yepes, 2012; Ponz-Tienda et al, 2013).



	Dur	S.S.	ES	EF	LS	LF	TF	FF	Resp	Zone	Area
Walls A	6	0	0	6	19	25	19	0	St Mg	Zone A	
Walls B	5	6	6	11	29	34	23	3	St Mg	Zone B	
Install A	3	11	11	14	25	28	14	0	St Mg	Zone A	
Install B	2	11	14	16	34	36	20	8	St Mg	Zone A	
Floor 0A	8	16	16	24	28	36	12	0	St Mg	Zone A	
Floor 0B	6	17	24	30	36	42	12	0	St Mg	Zone B	
Prepare St	5	11	11	16	37	42	26	14	St Mg	Zone A/B	
Floor 1A	11	23	30	41	42	53	12	0	St Mg	Zone A	
Floor 1B	11	34	41	52	53	64	12	0	St Mg	Zone B	
Floor 2A	11	45	52	63	64	75	12	0	St Mg	Zone A	
Floor 2B	11	56	63	74	75	86	12	0	St Mg	Zone B	
Floor 3A	11	67	74	85	86	97	12	0	St Mg	Zone A	
Floor 3B	11	78	85	96	97	108	12	0	St Mg	Zone B	
Floor 4A	11	89	96	107	108	119	12	0	St Mg	Zone A	
Floor 4B	11	100	107	118	119	130	12	0	St Mg	Zone B	
Stair 1	3	123	123	126	132	135	9	9	St Mg	Stairs	
Stair 2	3	126	126	129	132	135	6	6	St Mg	Stairs	
Stair 3	3	129	129	132	132	135	3	3	St Mg	Stairs	
Stair Com	5	111	118	123	130	135	12	12	St Mg	Stairs	
Ptret	3	132	132	135	132	135	0	0	St Mg	Zone A/B	

Figure 8: Phase schedule representation, Responsibles and Zones with Matrix Pro

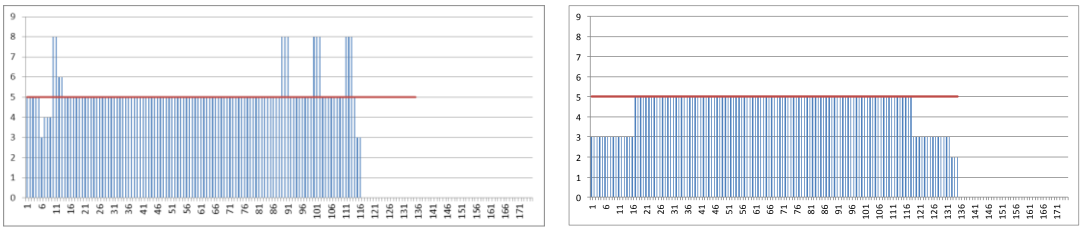


Figure 9:Optimization Model for the Phase Structure with Matrix Pro

All of Excel's features can be used, even allowing to create different reports as temporal diagrams or Line of Balance (LBM) charts (Figure).

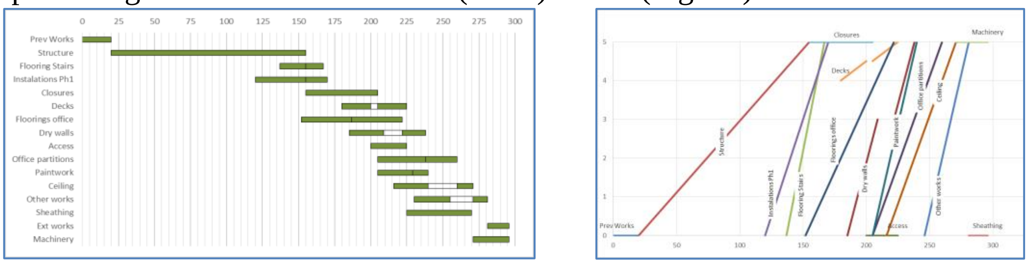


Figure 10: Main Program representation with temporal and LBM diagrams

LOOK AHEAD SCHEDULE AND WEEKLY WORK PLAN

To manage the pre-requisites, restrictions, look-ahead programs and weekly work plans, *Matrix Commitments* was used. For the look-ahead programs, temporal charts of 5 weeks (4+1) was selected in the WWP sheet manager, and 2 weeks (1+1) for the weekly work plans (*Figure*).

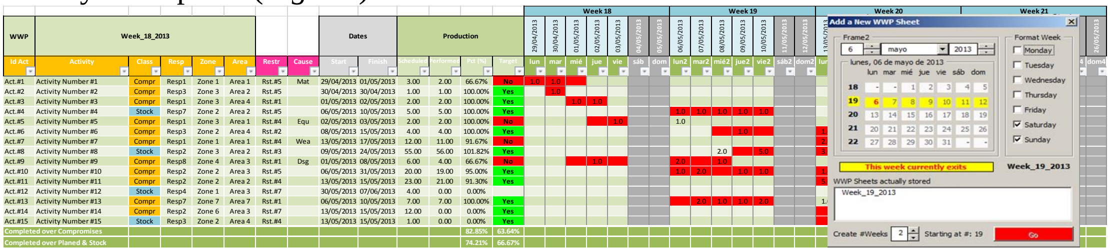


Figure 11: Look Ahead Program with Matrix Commitments

MEASUREMENT, LEARNING AND CONTINUAL IMPROVEMENT

The control and continual improvement process is developed in two levels with different goals: the schedule level and the commitments level (Figure 3).

The commitments level control with PPC measures helps the team to work on the basis of learning the continual improvement process. The PPC index does not measure production rates; it teaches the team to improve the production rates from what was "effectively done" to what "can be done" from now into the future.

The schedule level control with the EVM, provides cost and schedule deviations values on productivity and economic terms from what was "really done" of the Weekly work plans.

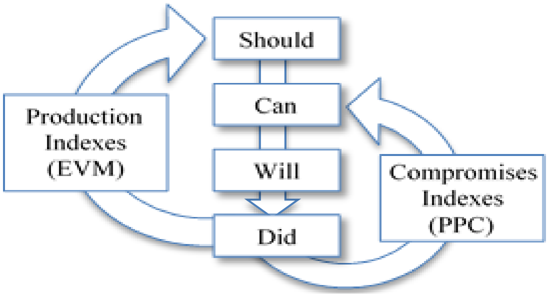


Figure 3: Integrated EVM and PPC for continual improvement

Both methods work together efficiently to reduce variability and to make the work more predictable, closing the total improvement process (Figure 4). From the "done" to the "can be done", up to the "should be done" in terms of production through the continual learning process.

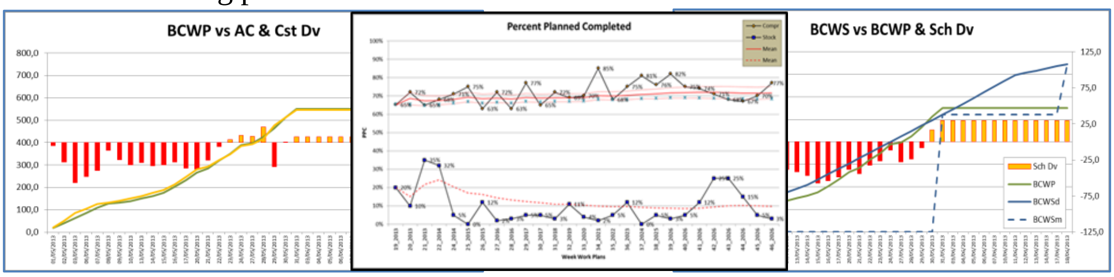


Figure 4: Cost Deviation, Schedule Deviation, PPC and Pareto Chart

Kim and Ballard (2000) found that EVM method's validity is compromised in account for "unbalanced process flows and lack of predictability". Advances are needed in order to validate and integrate new production control approaches in terms of workflow and value generation, with current practices (Kim, Kim and Cho, 2015).

Nevertheless, EVM, together with the commitments level control, allows to effectively recognizing the root causes of deviations, contributing to the reliability of workflow.

CONCLUSIONS

In this paper, a new approach for the representation and computation of projects for the Last Planner System of Production Control is presented. This approach is integrated with the management of the Earned Value and ad-hoc complex optimization models. The proposal has been implemented in an add-in for Excel called *Senda Matrix*. This add-in takes into consideration the feeding and work GPRs, allowing the splitting of activities in a discretionary way, avoiding the interruption of the critical path and the reverse criticality issue, as well as including the balance of process flows by integrating EVM with PPC calculations.

Senda Matrix is a Free and Open-Source Software (FOSS) under License Creative Commons–CY (Attribution), and is used in different undergraduate and postgraduate courses at Universidad de Los Andes at Bogotá, Colombia, and Universitat Politècnica de València, Spain (Pellicer and Ponz-Tienda, 2014; Pellicer, et al., 2015). It allows to effectively implementing advances. A base model for the integration of metrics is developed to serve as a basis for future developments.

This add-in for Excel has been developed from academia to support AEC industry and Lean practitioners that can use it in order to overcome some of the problems of the current commercial applications and help them make better decisions.

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TOP DOWN VS. BOTTOM UP APPROACHES REGARDING THE IMPLEMENTATION OF LEAN CONSTRUCTION THROUGH A FRENCH CASE STUDY

Fabrice Berroir[1], Lahcène Harbouche[2], Conrad Boton[3]

ABSTRACT

In order to sustainably reduce wastes on construction sites, companies need to know where they should start their Lean journey and how the different Lean tools can practically be used together. Based on a two years research project in Paris involving 15 construction sites of a major French company, this paper compares a top down and a bottom up implementation approach. During the first part of the project, Lean actions were decided by top managers using company-wide indicators. The focus was put on 5S programs in order to bring stability, to introduce Lean thinking on sites and because it is traditionally described as a part of the foundation of the "Lean House". In contrast, during the second part of the project, each use of Lean tool (5S, quality control, Last Planner System) was decided with sites crews according to local measures. Implementation methods, performances, commitment of the crews and sustainability of both approaches are discussed using case studies in order to provide practical recommendations on the use of Lean tools. Ultimately the paper shows how digital technologies can support field implementation by improving data collection and decision making.

KEYWORDS

Lean construction, 5S, Last planner system, Field implementation.

INTRODUCTION

Lean Construction is getting increasing attention from companies since it appears to be one of the most prominent improvement approaches within the construction industry. Consequently a subsidiary of one of the world's leading construction groups in France decided to implement Lean on its construction sites. Although Lean tools have shown their efficiency on construction sites as described in the literature and as demonstrated in previous Lean projects in this company, the change remains hard to achieve and above all is hard to sustain.

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According to Picchi and Grandja (2004), Lean in construction in 2004 could be described as a fragmented set of tools: The focus was on applying Lean tools in specific situations to address specific issues (such as flow, wastes, variability). This situation was confirmed by other researchers (e.g, Höök and Stehn, 2008) and describes well the situation encountered by the research team at the beginning of this project. Shifting to a global Lean application is crucial as Liker stated in *The Toyota Way* in 2004: Lean is not just a set of tools but a global improvement system. Therefore, a global implementation strategy is necessary. According to Höök and Stehn (2008), Lean implementation can be described as a top down (project performance goals set by top management) or a bottom up approach (person focused). The work described in this paper developed a bottom up approach in the context of a major French construction company, compared it with the top down way, and showed how some of the main Lean tools can practically match together.

PROJECT CONTEXT AND METHODOLOGY

The project was launched in 2012 and was carried out by a research team external to the company. It aimed to develop and test a sustainable Lean approach in the context of a major French company's subsidiary, where the construction sites are highly independent. It focused on the structural building phase since it is considered to be the core of the activities of the company.

During the first year, the lean actions were decided by top managers using companywide indicators. The implementation strategy and the company's standards were reviewed according to the impact and to the sustainability of these actions. 10 building sites were involved in this part of the project. This Top down approach was chosen following the wish of the company leaders and because this is the way most consultants currently deploy Lean in construction sites in France.

During the second year, a bottom up approach was developed with the sites crews: based on local measures (measures of Value Added/Non Value Added activities, flow measures) the tools were implemented step-by-step so that people could learn from limits and mistakes. The implementation strategy was reviewed accordingly. 5 building sites were involved in this part of the project. Figure 1 describes the top down and the bottom up process of implementation used during the project:

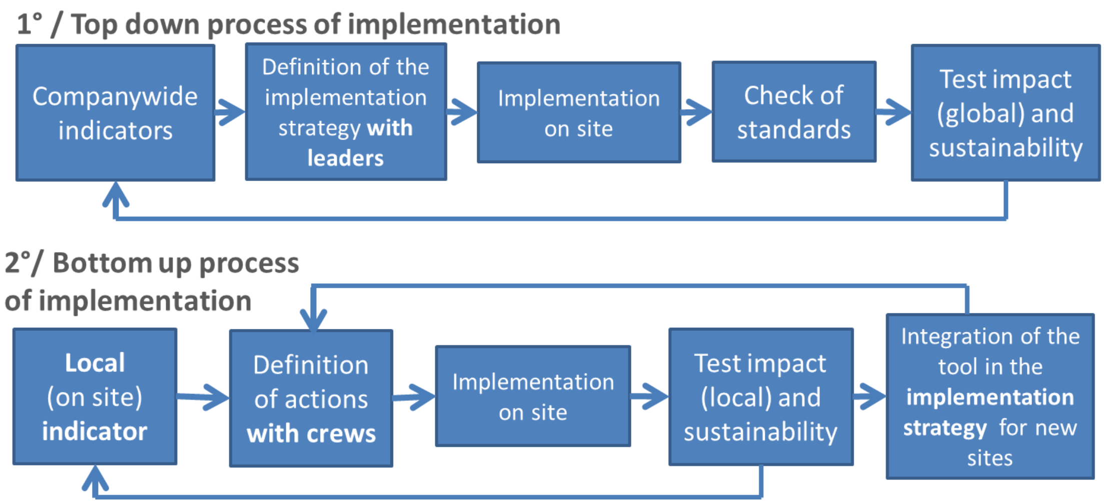

Figure 1: Top down and bottom up approaches during this project

THE «TOP DOWN» WAY

INITIAL STATE OF LEAN PRACTICES IN THE COMPANY

The representation from Höök and Stehn (2008) is a view of the classical model of the Lean House adapted to the context of construction sites (figure 2). It was used to define the weak points in the company's practices regarding Lean Construction:

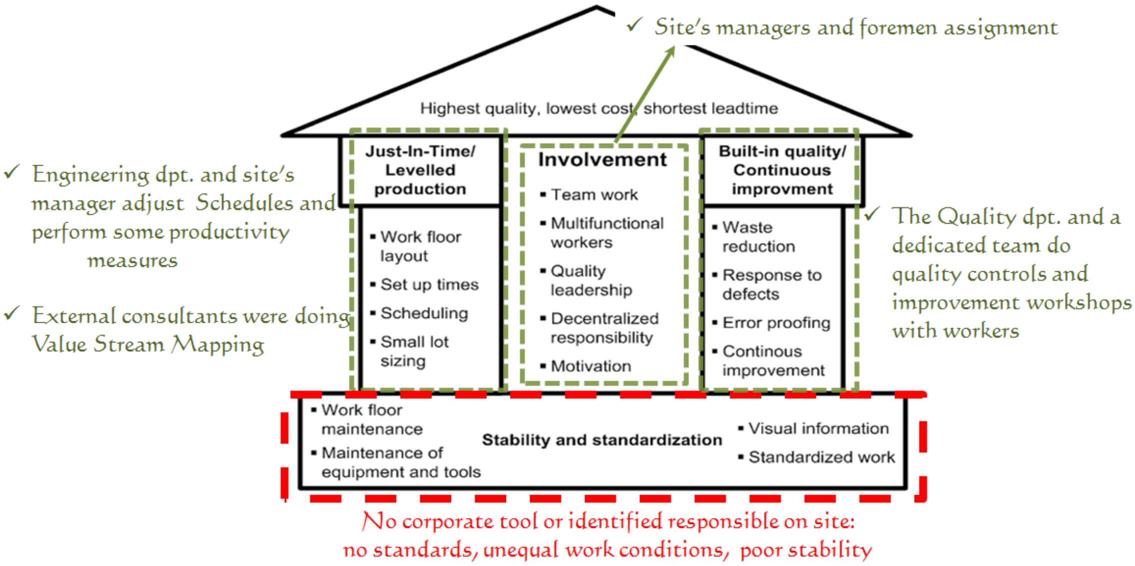

Figure 2: As-is of the company's practices regarding the Lean House based on a representation from Höök and Stehn (2008)

People (internal or external) were responsible to handle and improve Just-in-time aspects, quality aspects and involvement aspects, but no one was actually in charge of stability and standardisation (at the site and in the company). Thus, the foundation part of the Lean house appeared to be the weak point of the company's practices. It had an impact on sites performances, e.g., in a building site in Val-de-Marne, 2 months before the end of structural works, 70% of the available storage space was taken by structural steel. 50% of this steel was unnecessary material (mainly because of change orders after material delivery) stored throughout the project because of the poor work floor maintenance (figure 3) and got finally removed at the end of the project. Consequently, materials were stored on overloaded workplaces and deteriorating productivity. For example, laying beam reinforcement lasted 10 to 15 minutes but required up to 2 hours of searching time.

Figure 3: Overloaded storage and workplaces due to a lack of organization

5S TO BRING STABILITY AND STANDARDS

In this context, according to the (result-based) indicators available in the company, the company leaders decided to use the 5S tool in order to bring stability and standards on sites. 5S is a basic method of the Toyota Production System for clean-up and organisation of the workplace explained namely by Liker (2004). 5S programs can be successfully applied in construction, even at a wide company scale. For example, Leino, Heinonen and Kiurua (2014) describe a 5S program where 5S workshops involved 2,770 employees at 190 jobsites during 1 week in Finland. After this program, weekly inspection indices rose by 3.4 percent points and the number of accidents related with slips and trips were reduced. (Whether this case is really top-down or not is discussed later).

An impact on productivity thanks to the use of 5S is also expected since it directly deals with wastes such as waiting, searching and moving.

The 5S tool heavily focuses on the field and, as workers do the Lean transformation of their own workplace, it is often described as a bottom up tool. However, the 5S actions were actually decided by the company leaders and not by the sites' crews themselves; therefore it was in reality a top-down approach. In this context, the implementation protocol was:

1. Gemba Walk with site managers.
2. 5S Training of all the sites workers, managers and main sub-contractors.
3. 5S Actions in the storage zones with foremen and project manager ("Sort", "set in order"): A weekly review of the storage zone was done subsequently with project managers and foremen to manage internal logistic and supply.
4. 5S Actions on the workplaces with foremen and workers ("Sort", "set in order", "shine")
5. Spread good practices to all sites, define new standards and apply standards.
6. Follow up inspections and measures.

Was it efficient and sustainable?

In order to evaluate the integration of the 5S methods in the sites practices and in order to continuously define key actions, sites managers (or foremen) and researchers inspected the site and calculated separately a "5S rating" (in percentage) according to a standard reference table. This measure was considered as reliable because the mean gap between the rating given by the site's crew and the external assessor rarely exceeded 5%. This score was communicated to the directors and used as a non-financial companywide process indicator. Measuring and reporting progresses aimed to bring out motivated people in order to accelerate and maintain the improvement dynamic. Moreover, bad ratings (under 50%) or important decrease aimed to enable a quick hierarchical reaction and newer 5S actions. This measure was also used to evaluate the results of the 5S tool itself and of its implementation strategy by comparing it to the other indicators available in the company. The study of this 5S rating showed that:

- At the end of the first year, all sites were above a 50% rating. Whenever a site was under this warning level, site's managers reacted quickly (either because they were conscious of the risk of further deterioration or simply because of hierarchical orders). Such a 5S program was thus efficient to prevent dangerous situations (such as fig.3) and to set up standards.

- Most sites improved their 5S rating, (the mean rating grew from 52% to 67% in one year). But the sustainability remained questionable since, after a few weeks in autonomy the 5S rating tended to decrease.
- Few construction sites managed to reach the 80% rating or more. Whereas workers and managers considered that being over a 50-60% rating was relevant, getting over 80% didn't seem worth it to them.

Although it achieved to bring companywide standards (which was actually the initial objective), the top-down implemented 5S was not really sustainable. Incentive bonus regarding the respect of 5S and safety standards, non-numerical scales or rating done by workers themselves were tested and gave very similar results. The same observation applied to other improvement actions separately implemented on sites with a top-down approach (e.g. Value Stream Mapping or quality control): Actions were mostly done because of hierarchical pressure and not because of a true continuous improvement culture. Three limitations of this top-down approach have been emphasized by this case study.

Fragmented tools application is not Lean:

In *The Toyota way*, Liker (2004) already warned against a widespread misconception of Lean. He explained that many companies confused 5S with Lean and he told the story of shinning workshops thanks to 5S where quality, productivity or cost actually didn't improve. Same misconception is likely to exist in construction because of some current consultancy practices. The 5S tool when used alone did not enable to manage what was needed to fulfil the tasks on time: Most 5S actions consisted of handling materials that should actually not have been on the site.

No person centred approach:

According to the *Toyota way* (Liker, 2004), the improvement strategy must be able to bring a real cultural change. Whereas conventional organizations focus on getting things from the employee, Mann (2005) advocates for a different approach focused on people: "Focus on the people and the results will follow. Focus on the results, and you'll have the same troubles as everyone else—poor follow-up, lack of interest, no ownership of improvements, diminishing productivity". It is typically what happened here with the dogmatic use of Lean tools. Also in the case described by Leino, Heinonen and Kiurua (2014), the authors insisted on the importance of involving workers in a bottom-up way.

Insufficient performance indicators:

Sarhan and Fox (2013) explained that the kind of indicators the practioners and managers choose will directly and heavily influence the implementation results of Lean applications. In the context of the project, the decisions were taken and their efficiency was evaluated using the following companywide indicators:

- Financial result: This is the traditional (result-based) performance indicator of the site managers. The actual numbers were never communicated to researchers (or even directors) at the time of the implementation. Moreover financial indicators were not effective in identifying the wastes and their root causes as stated by Sarhan and Fox (2013). In this context, the financial KPI didn't enable to define and justify Lean actions at an operational level.

- Safety indicators (Accidents rates and safety visits): A correlation with 5S rating was done (showing a positive influence of 5S) but the statistical sample was too small to give robust results.
- Process performance indicators and productivity: Lean Construction relies heavily on such indicators. In the company, some measures were done by internal services but only used at a company level to define top down actions. The measures and their meaning were never communicated to workers.

Given this lack of indicators, the first step of the bottom up approach developed during the second part of the project was to use operational indicators that are relevant for workers and middle managers.

AN INCREMENTAL BOTTOM UP APPROACH

LEAN ACTION DECIDED WITH THE CREWS USING LOCAL INDICATORS

Considering the limits of the top down approach, the second part of the project focused on local performance indicators in order to define the Lean actions with the crews instead of applying dogmatically the decisions of top managers. As well as in the case described by Tillmann, Ballard and Tommelein (2014), the idea was to "implement only techniques that will truly add value to the field."

Therefore, the Value and Non-Value Added analysis can be successfully applied in construction (e.g. Eswaramurthi, 2013). It brings usable data from the field in order to identify, show and reduce wastes. A VA-NVA analysis was done on another site in Val-de-Marne to show wastes in the assembly process of steel beam reinforcement. The measures showed that 48% of the time spent by the workers was waste (typically unnecessary searching and handling of material due to overloaded storage area as shown on figure 4). The results were analysed with the crew and site's managers.

Figure 4 : Initial state of the assembly of steel beam reinforcement

Before the measures, the site's crew considered that the organisation of the storage and of the delivery was only a subcontractor's task. Showing an improvement area for the whole site's performances, the measure triggered more communication between both stakeholders. They decided to apply 5S in the inventory, Just-In-Time delivery, new pre-wrapping of the steel bars and Kanban to launch beams in production (figure 5). This actions increased productivity, quality and reliability (table 1).

Figure 5: State after the Lean actions

Table 1: Impact of the VA/NVA on steelwork

	Before	After
Mean cumulative time per beam	8h	5h
Quality	50% of the produced beams reworked	10% of the produced beams reworked
Work finished when planned?	NO	YES

This case is an example of the person centred approach asked by Mann (2005). Workers in Maison-Alfort were involved in the analysis of the results, and proposed new solutions. Thus they decided to apply the 5S on the worksite. The storage zone was cleaned once a week and the good results in the storage area motivated the site's crew to take more 5S action on their own. This bottom up application of 5S was sustainable as 5S rating on the site stayed above 75% during the last 3 month.

MEASURES OF FLOWS TO DEFINE THE ACTUAL CONSTRAINT

The previous example worked not only because workers felt more involved but also because the right measure was done on the actual constraint of the site. On the contrary, another VA-NVA analysis in a site in Haut-de-Seine did not achieve such results: the chosen team for the measures was the one that, according to the foreman, had the lowest efficiency and a bigger need for improvement. Value Stream Mapping showed subsequently that it was not the actual bottleneck of the site at that moment. Referring to the TFV principles (Bertelsen and Koskela, 2002), it can be argued that the foreman's view was a "transformation view" focused on the activities, whereas a flow view at the scale of the whole site was necessary to define improvement actions.

Pérez, Costa and Gonçalves (2013) summarize three different methods to measure flows and identify the associated wastes: Value Stream Mapping, Overall Equipment Efficiency (OEE) and Process and Flow Diagram. The three methods were tested. Because of the context of structural work (where the use of a crane is predominant) a focus was done on OEE measures on the crane. The impact remained however quite limited or impossible to measure. Although all three methods provide a simple understanding of flows and showed a lot of wastes, it took usually 2 to 3 weeks to measure, analyse and define actions. It was then too long to efficiently improve non repetitive activity.

Another limitation was the variability that affected the sites. For example, waiting times measured on the crane varied from 5% to 35% on the same crane in the same week. Moreover, most of the wastes measured by OEE were due to the lack of planning reliability that could arguably be addressed using Last Planner System.

INTEGRATION OF LEAN IN THE DAILY ACTIVITIES USING LPS

In the previous cases, Lean practices were still not integrated in the activities of the site's crews. In order to focus on variability and to control production of the whole site, LPS was added incrementally.

First of all, the capacity of each crew was measured in order to balance the different teams: some areas were finished in 3 to 5 days by some teams, whereas the others needed only 2 to 3 day. The decomposition of the zone to build and the capacity of each team were adjusted so that each task could be done in 2 days. Every week, Weekly Work Planning meetings were held; it enabled the team to keep the balance within the tasks and to define the new actions to focus using a PPC indicator. The objectives were adjusted by team leader and foremen according to their actual capacity every week during the collaborative meeting. The actual time per floor measured decreased from 25 day per floor to 12 days and got more reliable (figure 6):

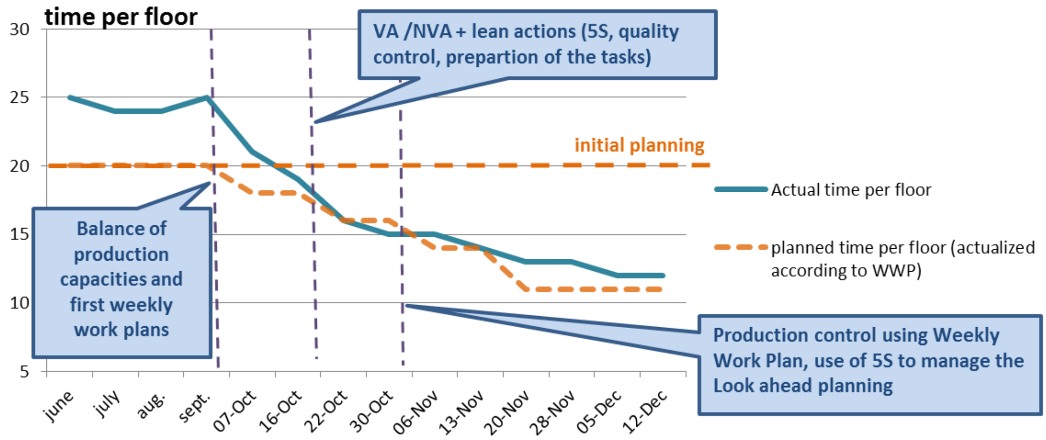

Figure 6: Actual and planned time per floor

In order to reduce variability, VA/NVA measures focused on the tasks with low PPC. Lean actions were set up by the crews accordingly. For example, using 5S and a better preparation, the maximum time to lay one column got divided by 3 (figure 7).

Mendes (1999) introduced a bottom up approach of LPS. Very similarly, LPS tools were added step-by-step during the project. In the first month, PPC measures showed tasks that were not finished on time because of missing pre-requisites. Consequently, the site's crew decided to incorporate make ready process and look ahead planning to manage the prerequisites. Instead of being an additional process for the site's managers, 5S and quality control (inspection during delivery) were thus integrated in the management of the whole site's prerequisites.

More than 1 month delay was estimated by the site's crew for the end of the structural work. Ultimately, it finished one week ahead of the delivery date with a PPC that grew from 70% in June to 90% in November.

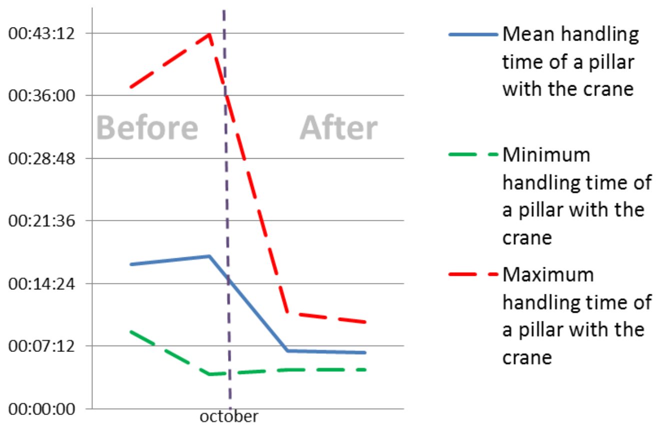

Figure 7: Reduction of the variability of the pillar laying task

LIMITS AND FUTURE RESEARCH

Because of the higher need for measures on site, the number of sites involved in the project was smaller in the bottom up phase (5) than in the top down phase (10). To facilitate learning, the new tools were integrated step-by-step in order to enable crews and managers to identify the actual improvements, instead of bringing them a "turnkey" solution. Consequently, the authors advocate for further tests on a wider scale and for a longer duration, in order to give more data on site's performances and to confirm the better sustainability of the bottom up approach.

Focusing on local performance indicators was the key point of the bottom up Lean implementation during this project. However it was also one of its weaknesses because qualified assessors and time spent by the crews were necessary in order to measure and to analyse sites practices. Choosing the best indicators and define how to measure them efficiently is thus a crucial field of research. New Technologies (e.g. RFID, BIM) bring it new perspectives of data collection and monitoring on sites. The local data it would bring can enable a more accurate management of the prerequisites and of 5S on sites.

CONCLUSIONS

This paper presented cases studies from two years of Lean implementation in a French major company. More than a set of separate tools, each one answering to a given problem, Lean is a philosophy and its implementation requires a well-suited strategy. Therefore two approaches have been practically tested on sites and discussed on a total number of 15 building projects in France. The top down implementation is based on the conviction of company leaders who rely on global indicators. With tools such as 5S, it enabled to bring more standards in the company but ended in a fragmented and dogmatic tools application. Moreover, most actions were not actually sustained and their economic efficiency was still debatable because of a lack of indicators.

A bottom up implementation was developed with the sites' managers and crews based on local process indicators. Lean tools were integrated incrementally to facilitate learning and answer to the actual needs of each site. VA/NVA analysis enabled a real awareness of the potential of improvement on workplaces. Thanks to flow indicators, the actual constraint of the site could be identified. Ultimately, Last Planner System's tool of production control enabled to monitor improvement actions and to integrate them in the site's daily practices. Variability, wastes and overall delay were thus actually reduced. To start their Lean journey, many companies can be interested in a Top down implementation such as tested during the first part of the project. This work shows the limits of this approach and provides an alternative way adapted to sites' practices.

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EXPECTED LEAN EFFECTS OF ADVANCED HIGH-RISE FORMWORK SYSTEMS

Hisham A. Abou Ibrahim[1] and Farook R. Hamzeh[2]

ABSTRACT

The selection of formwork systems in high-rise buildings is often governed by their competence in optimizing concrete activities in an isolated manner, without relating this choice to the entire construction workflow. Known research efforts do not address this important aspect in analyzing high-rise formwork technologies, and formwork selection is usually left to constructors' experience, and corresponding organizational knowledge. In this context, this paper studies the role of formwork systems in high-rise construction from a lean perspective and analyzes this role in shaping not only the progress of concrete activities, but the entire construction sequence. Employing lean concepts, the paper investigates advanced high-rise formwork systems versus traditional ones to better advise scholars and practitioners. Results highlight the importance of advanced high-rise formwork systems in streamlining the workflow of concrete and other downstream activities, allowing for more waste reduction, smaller work batches, less inventory, and safer working environment. This study is a conceptual framework for future related works involving case studies and field investigations, and may be further developed to target more aspects of high-rise construction.

KEYWORDS

Workflow, Logistics Planning, Inventory Control, Waste Reduction, Safety.

INTRODUCTION

High-rise construction witnessed a rapid growth in the past few decades. Several aspects of high-rise projects, from architectural and structural designs, environmental strategies, lifting techniques, firefighting systems, construction methods, and safety procedures have seen major developments. However, high-rise projects encounter several challenges throughout their construction stages. Beyond engineering and construction difficulties, planning of logistics appears to be a major concern on such projects. Most skyscrapers are built in tight land lots in city centers with serious limitations on available storage areas to the extent that sometimes there are none available. This fact imposes high pressures on the supply chain management where timely and proper material delivery is important. Other difficulties encountered on

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high-rise construction can be related to building design complexity, technologies used on site, labor availability and skills, adequacy of the methods followed, and capacity of planners to foresee the dynamics of their site and proactively shape its progress.

While technical constraints are resolved by advanced engineering solutions, construction constraints can be removed by better planning and scheduling, using advanced technologies on site, and by employing lean ideals. Several studies targeted the application of lean principles in various high-rise construction aspects (Sacks et al., 2005; Bae and Kim, 2008;Al Hattab, Zankoul and Hamzeh, 2014), whereas other efforts investigated the use of lean principles in enhancing construction workflow in general (Arbulu and Ballard, 2004; Hamzeh, Ballard and Tommelein, 2008; Yassine et al., 2014). However, none of the literature reviewed addresses the role of formwork systems in shaping the workflow of concrete and non-concrete activities in high-rise construction, and their impact on the application of lean concepts.

In this regard, addressing the role of formwork systems in directing construction workflows on high-rise projects is a novel approach that allows researchers and practitioners to link the choice of formwork systems to construction workflows on one hand, and to logistics planning, inventory dynamics, crane schedule, labor and material delivery, and safety procedures on the other. Accordingly, this paper aims to: (1) compare advanced and regular formwork systems, (2) track construction workflow changes, and (3) underline major lean principles enabled by the use of advanced formwork technologies.

RESEARCH BACKGROUND

The repetitive nature of high-rise construction helps planners maintain workflow continuity, decrease labor and equipment idle times, reduce hire and fire actions, and take advantage of the learning curve effects (Ranjbaran, 2007). However, these repetitive activities advance simultaneously in vertical and horizontal directions and may create spatial constraints that hinder the execution of work (Thabet and Beliveau, 1994). To account for these constraints, practitioners and researchers sought scheduling solutions to navigate the execution of tasks under these restrictions. Since the drawbacks of applying the Critical Path Method (CPM) to schedule repetitive tasks were investigated in many studies, (Hegazy and Wassef, 2001), alternative scheduling techniques using the Line of Balance (LOB) method were employed. LOB allows operations on site to continuously flow from one activity to another by balancing different tasks, resources, and space simultaneously (Hegazy, 2002). While some researchers worked on combining both the CPM and LOB methods to enhance work scheduling in repetitive construction (Suhail and Neale, 1994), other researchers used 4D modeling techniques provided by Building Information Modeling (BIM) technologies to simulate the construction sequence and to proactively account for possible on site clashes (Staub-French and Khanzode, 2007).

These scheduling solutions (LOB, LOB-CPM combined, and 4D scheduling) assume the availability of labor and material necessary to execute the work at the right time and location; however, this is not always the case. Delays and cost overruns are often attributed to the failure of delivering resources to work areas when needed, especially on high-rise projects. Hence, a clash free schedule is not necessarily translated into smooth workflow on site, thus highlighting the importance of day to day site dynamics including delivery procedures, hoisting capacity and speed, and crane availability. In this context, the choice of formwork system greatly influences the workflow of concrete and non-concrete activities. Core-wall and floor formwork systems directly affect concrete cycle times and indirectly influence the interlocking flows of walls, shafts, and slabs where different tasks from different trades are involved. For instance, formwork lifted by a crane would interrupt the crane schedule and may delay the delivery of materials to other work areas for several trades, resulting in significant delays and additional costs. Therefore, the selection of a convenient formwork system is a key decision on every high-rise construction.

Several parameters, presented in Table 1, affect the choice of formwork systems. While internal parameters fall under designer and contractors control, external ones are affected by owner requirements, project milestones, project location, and corresponding local rules and regulations (Gnida, 2010). Other studies linked the selection of the formwork system to building height and weather conditions (Ciribini and Tramajoni, 2010). Based on these parameters, many contributions were made to improve the efficiency of formwork systems resulting in wide variety of formwork types. In addition to the previous parameters, the selection of formwork is mainly governed by cost considerations where contractors try to minimize the total cost of the concrete package in isolation of the indirect costs of the resulting schedule.

In this context, the paper presents scholars and practitioners a comprehensive understanding of formwork role in high-rise projects, where advanced systems are expected to enable the realization of several lean principles such as waste reduction and workflow enhancement.

Table 1: Parameters governing the selection of formwork systems (Gnida, 2010)

Internal Parameters		**External Parameters**	
Geometry	• Repetitive • Simple/ Complex • Changing Geometry	Space	• Existing Road or Building • Storage Area • Assembly Area
Concrete	• Rate of Pour/ Concrete Pressure • Concrete Finish • Curing Time	Wind	• Wind Load
Sequence of Work	• Cycle Time	Crane	• Capacity/ Type • Availability • Boom Reach
Formwork Choice	• Existing Formwork Material to be Reused • Rental or Purchase • Best Value for Current Project Vs. Flexibility for Future Projects	Safety	• Special Requirements Needed
		Construction Planning	• Milestones • Working Schedule/ Shifts • Project Duration • Holidays
		Local Rules/ Regulations	• Permits • Restricted Noise • Safety Requirements

RESEARCH METHOD

This paper investigates the role of high-rise formwork systems in shaping the workflow of concrete and non-concrete activities. It also addresses the effects of formwork choice in governing site dynamics, labor and material delivery, inventory size, logistics planning, and cranes' schedule. Comparing advanced and regular formwork systems, the paper underlines major differences from a lean perspective, and employs a process model to describe the workflow alterations in both cases. The paper concludes by highlighting major lean principles enabled by the use of advanced systems. Figure 1 illustrates the roadmap followed to achieve paper objectives.

Figure 1: Research Roadmap

RESEARCH LIMITATIONS

The paper investigates the role of advanced high-rise formwork systems based solely on theoretical analysis. Field data collection and case studies can be addressed in future efforts to provide required quantitative analysis.

FRAMEWORK DEVELOPMENT

ADVANCED AND REGULAR FORMWORK COMPARISON

Advanced and common core-wall formwork technologies used on high-rise projects are self-climbing systems, lifted using hydraulic jacking mechanisms independent of any external crane or lifting equipment. However, advanced systems are available as single or double jump formwork assemblies that jump two floors at a time. Another important feature that distinguishes advanced core-wall formwork systems is the shaft trailing platform attached to it as shown in Figure 2. The trailing platform could drop up to six floors down the core-wall formwork allowing elevator specialists to start fixing elevator rails and accessories early on (Double-Jump System, n.d.).

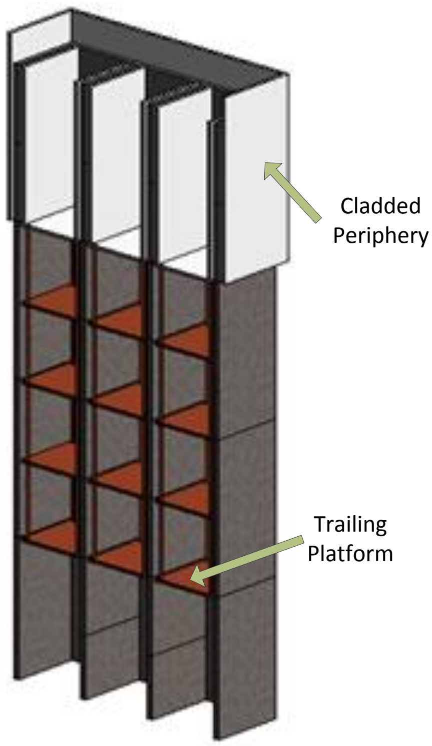

Figure 2: Schematic representation of advanced core-wall system

As for the floor's formwork, practitioners try to benefit from the repetitive nature of slab construction by standardizing formwork size and material, and by maximizing the number of formwork reuse. In this context, table forms are widely used to decrease formwork setup time and to decrease slabs' construction cycle time. But, regular table forms are crane dependent and congest the crane schedule every time they are moved from one floor to another. Regular vertical forms are also modularized and moved by cranes from a floor to another. On the other hand, advanced formwork technologies provide innovative perimeter system which combines construction and safety requirements. A self-climbing system is used to form vertical elements such as columns and walls independent of floor slab construction. The jacking points of the system are above floor slab giving clear access for slab formwork, reinforcement, and concrete pouring below the system, as shown in Figure 3. The key advantage of the perimeter system is the accelerated construction of columns and slabs that progress independent of each other. The system can also provide lifting services to move slab table forms internally without any use of the tower cranes (Double-Jump System, n.d.).

Figure 3: Advanced perimeter system (Double-Jump System, n.d.)

For the purpose of comparison, Table 2 serves as a reference for the major differences between regular and advanced formwork systems discussed in this study.

Table 2: Advanced and regular formwork comparison

Feature	Regular Formwork System	Advanced Formwork System
Self-Climbing Core-wall Formwork	✓	✓
Core wall Formwork Internal Lift	X	✓
Core wall Trailing Platform	X	✓
Perimeter System	X	✓
Internal Table Lifting Capacity	X	✓

CONSTRUCTION WORKFLOW DIFFERENCES

To examine the role of formwork in shaping construction workflows, two process maps, illustrated in Figures 4 and 5, were developed to trace the differences in the construction sequence resulting from the use of advanced and regular formwork systems. While the trailing platform allows internal lifts specialists to start fixing lift rails and necessary accessories early on, elevator related tasks would not start until finishing core-wall construction in the case of regular formwork. Accordingly, service elevators can be made functional before final core-wall erection and can be used to hoist labor and material. Another schedule difference between the two cases occurs at the columns (walls) - slabs construction interface. While advanced systems allow the progress of vertical and horizontal elements independently, regular formwork systems are bound to the column (walls) – slabs sequence in every floor.

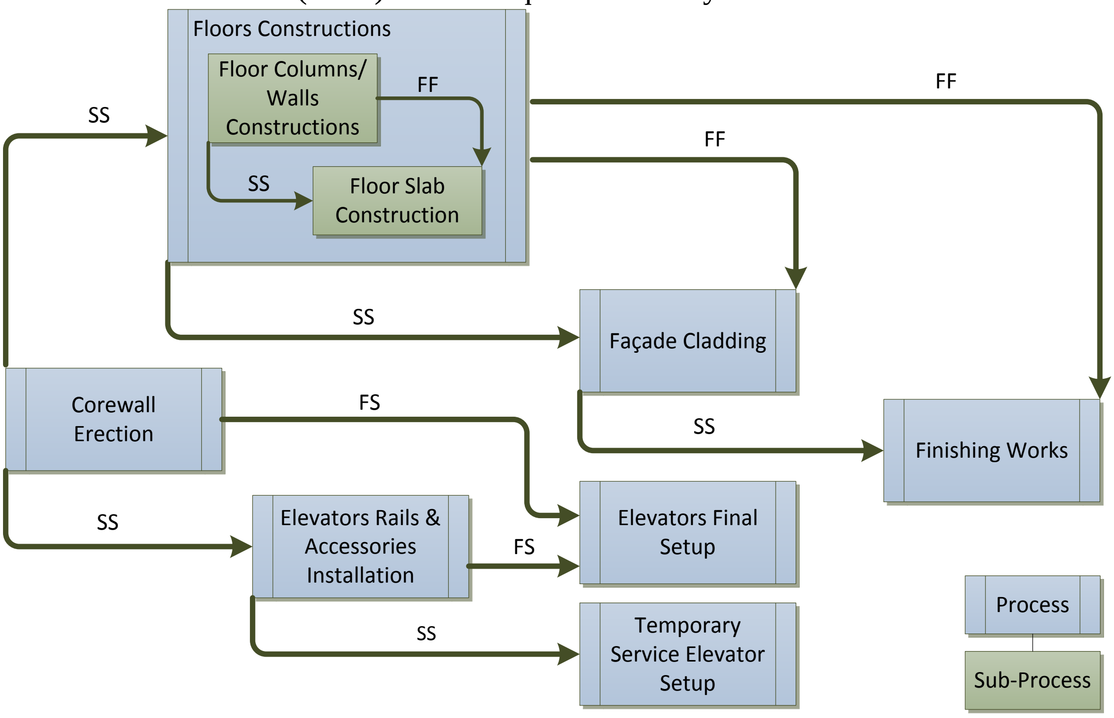

Figure 4: Construction process map using advanced formwork systems

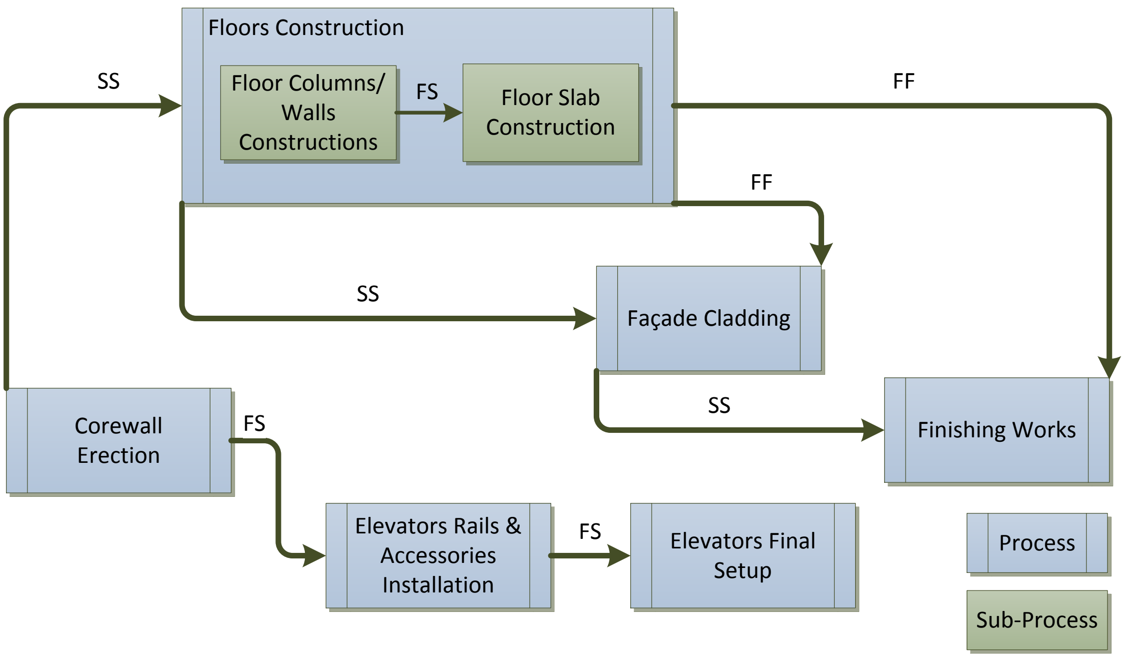

Figure 5: Construction process map using regular formwork systems

(SS: Start to Start, FF: Finish to Finish, FS: Finish to Start)

RESULTS AND DISCUSSION

WORKFLOW ENHANCEMENT AND CYCLE TIME REDUCTION

Advanced formwork systems enhance construction workflow on several fronts. The shuffling of construction sequence supported by the trailing platform allows the use of buildings service lifts early in the execution phase to transfer labor and material into the building, necessary to boost finishes and MEP activities. This fact decreases the demand on external hoists and tower cranes that are made available for other critical activities such as external cladding, and heavy material lifting. On one hand, the independent progress of columns and slabs, enabled by the self-climbing perimeter system, helps streamline both activities together and reduce the risk of one process delaying the other as in the case of regular formwork. It also boosts the production rates of both activities due to learning effects. On the other hand, advanced core-wall systems, like the case of double-jump system, can jump two floors at a time leading to significant reduction in cycle time; the work can be literally halved. For instance, steel fixing activities are done only once every two floors, and the same concept applies to concrete pouring as two consecutive floors are poured together. Other time consuming activities such as surveying operations, formwork alignment, and reinforcement inspections are also optimized to boost core wall construction speed. Therefore, as the number of cycles is largely decreased, the construction time undergoes substantial drops. Even with the single jump option, the system has been proven to reduce the cycle time to three to four days per floor (Naylor, 2006), especially that the formwork is totally isolated from external weather conditions by cladded screens and the top formwork deck is free from mass constraints providing workers a safe and adequate working environment.

Figures 6 and 7 schematically illustrate the expected differences between both schedules. First, production rates are expected to be higher in the case of advanced systems due to core-wall double-jump construction and the released cranes' and hoists' schedules. Second, elevators' installation starts and ends earlier, with the elevators temporarily ready at core-wall mid-height as shown in Figure 6. Third, columns and slabs construction are streamlined with the possibility of independent progress.

WASTE REDUCTION

Advanced formwork systems target several aspects of waste usually encountered on construction sites. The system reduces the amount of material wasted to follow design standards as in the case of steel splices (or couplers) that are used once every second floor (in the case of double jump system). Nonetheless, material idle time is expected to decrease due to improvements observed in material delivery and inventory management. Moreover, the trailing platform allows the early occupation of core-wall shafts by lifts' crews; a working space wasted in the case of regular core-wall formwork. Advanced formwork systems also reduce unnecessary movements. In this regard, lifting crews and material which is usually performed by external hoists and cranes, which take longer time with increasing building height, is now boosted by the early use of building service elevators. Beyond the mentioned wastes, advanced formwork systems provide a well-organized working environment that reveal the sources of waste and brings them to surface. As the system pushes towards continuous flow of activities alongside smaller work batches, project managers can better detect wastes taking place and act proactively against them.

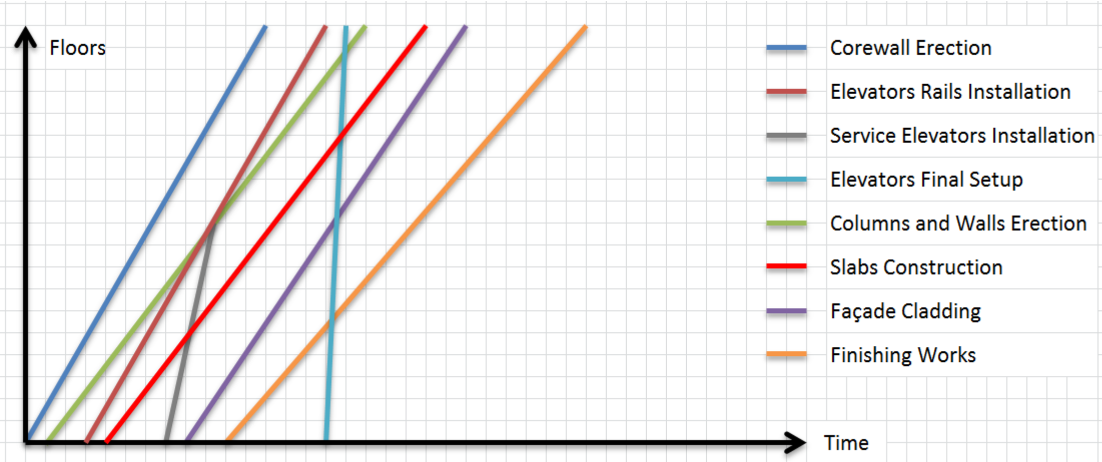

Figure 6: Schematic LOB schedule using advanced formwork

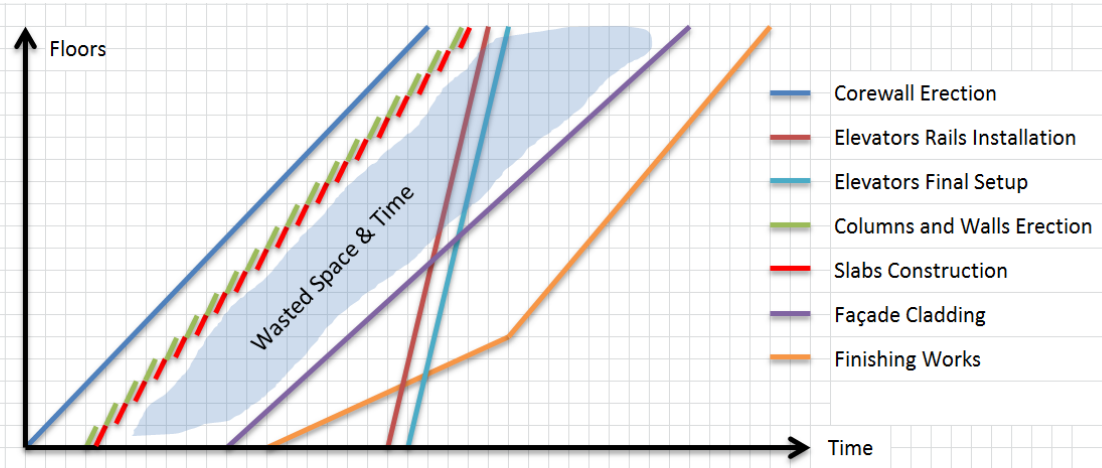

Figure 7: Schematic LOB schedule using regular formwork

REDUCED VARIABILITY AND INCREASED FLEXIBILITY

The repetitive nature of high-rise construction endorses the application of lean ideals. Repetitive tasks help stabilize the construction workflow and promote standardization and modularization. On the other hand, location based scheduling allows for continuous resource utilization and prevents spatial clashes where production rates of crews are adjusted and optimized. However, a clash free schedule and streamlined tasks are not enough to ensure smooth construction workflows on site. In reality, labor and material delivery to work areas is a major challenge on high-rise construction where hoisting speed and capacity decreases with increasing building height and involvement of multiple trades. In this context, the role of advanced formwork systems goes beyond just enhancing construction flows, but also improving labor and material flow on site. By releasing the constraints on the crane schedule and early use of service elevators, advanced systems contribute to increasing site flexibility and reducing batch sizes. As labor and material are efficiently moved to work areas, required batch sizes can be more accurately calculated with less variability, which is an important factor to stabilize the production on site as mentioned by Alarcon and Ashley (1999). Thus, the increased site flexibility is translated into more adequate logistics and inventory management potentially leading to smaller inventory sizes. This fact, along with tighter tolerances provided by advanced systems, empowers the use of prefabrication and off-site production which can boost construction speed, decrease cost, and increase site safety.

SAFER WORKING ENVIRONMENT

Advanced formwork systems provide innovative safety features. The core-wall formwork is totally isolated by cladding, protecting workers from falling and external weather conditions. The cladded formwork also waives the risk attributed to height changes that affects workers perception of danger and could disturb their response under hazardous situations (Hsu et al., 2008). Access to core-wall formwork on the top deck is provided by an internal isolated lift which is also raised by the system at each cycle giving safe access for workers. The perimeter system is also equipped with safety screens that cover several levels; providing edge to edge protection.

CONCLUSION

The role of formwork systems in high-rise construction goes beyond building the concrete core. The choice of the system shapes construction workflows and affects the planning of logistics, site inventory, and labor and material delivery to work areas. From a lean perspective, advanced systems are expected to streamline construction workflows, increase production rates, reduce wastes, decrease batch and inventory sizes, reduce variability and increase flexibility. This comprehensive understanding of the role of formwork systems is necessary to compare formwork options, and essential to reap full benefits when selecting one system or another. Further investigations are needed to quantify the paper findings, and to address other aspects of lean principles related to formwork design such as quality at bay and error proofing. Future studies also can link the selection of formwork systems to takt time calculation, and the use of pull systems and kanban cards.

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WHAT IS A GOOD PLAN?

Trond Bølviken[1], Sigmund Aslesen[2], and Lauri Koskela[3]

ABSTRACT

The word plan is in English both a verb and a noun, reminding us that *to plan* is a process resulting in a product, *a plan*. While the Last Planner System (LPS) is primarily focused on how *to plan* and control production, other planning concepts are more focused on the plan contents (*the plan*). A more explicit approach to the characteristics of a good plan could improve LPS as a planning concept. The paper proposes such a list, based on a discussion of the plan contents highlighted by the following planning concepts: Critical Path, the Location-Based Management System, Takt Planning, Critical Chain, Agile, Task Planning and the Last Planner System.

KEYWORDS

Last Planner System, Scheduling, Plan Quality.

INTRODUCTION

While Dwight D. Eisenhower (1957) said that "Plans are worthless, but planning is everything", the present paper is based on the view that "planning is everything, but plans are also something". While the Last Planner System[4] (LPS) has its main focus on the planning process (how *to plan*), many of the other planning concepts identified and discussed in this paper have their main focus on the result of the planning process, *the plan*. We have within Lean Construction over some years seen an increasing interest in some of these planning concepts[5]. This interest can be understood as an interest for the plan contents in addition to the planning process of LPS. The present paper proposes a set of criteria for a good plan. The hope is that these set of criteria can be used to improve LPS as a planning concept.

METHOD

The method used is theoretical reasoning based on authoritative sources. We have identified seven planning concepts relevant to our topic. First we give a short presentation of each concept and identify the main plan contents highlighted.

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[4] The Last Planner is a registered trademark of the Lean Construction Institute.

[5] We will in the paper use the terms *planning* and *scheduling* as synonyms.

Secondly we establish the structure of our proposed list, before we discuss some topics related to the contents of the list. Finally we conclude by proposing the list.

PLAN CONTENTS IN THE IDENTIFIED CONSEPTS

CRITICAL PATH METHOD (CPM)

CPM was first presented by Kelley and Walker (1959) and has later been developed in several variants (Kenley and Seppänen, 2010)[6]. As the name indicates, a main approach of CPM is to find, calculate and optimize the critical path of the project. The critical path is the sequence of activities (path) that has the longest duration and therefore is determining the total duration of the project. In order to establish and calculate the critical path, the plan must consist of activities with two fundamental features: Dependencies and durations. The duration of an activity can be determined by technical properties, (e. g. the time it takes for concrete to cure), but the main issue will usually be that the duration will be dependent upon the amount of manning resources allocated to the activity. Because there will be strong limitations to the flexibility of the manning of the project, CPM is therefore also focused on resource levelling. Different levels of resources result in different durations of tasks resulting in different critical paths through the project.

The dependencies between activities can be determined unambiguously by technical dependencies (e. g. the excavation for a building has to be done before one can start constructing the basement) or they have to be determined through the planning process[7]. Visually a CPM plan is usually shown as a Gantt diagram, focusing on the durations, or as a network diagram focusing on the dependencies.

Summing up, CPM is specially focusing on the following plan content:

1. The work breakdown structure, that is the tasks that will be the unit in the planning
2. The dependencies between tasks
3. Reliable estimates of the durations of each task
4. A optimal level of resources
5. The optimal project duration

THE LOCATION-BASED MANAGEMENT SYSTEM (LBMS)

As indicated by the name, LBMS (Kenley and Seppänen, 2010) is basically focused on the location where an activity / work package is to be carried out. The goal is to make a plan where only one activity at a time is carried out in each location (zone) and where resources can move from one location to another without waiting. In construction, production is done by resources moving through the product instead of (as in manufacturing) the product moving through production. LBMS is therefore a

[6] There is a large amount of literature on CPM. Over 40 reference books are used at universities in the USA (Galloway, 2005). Good presentations of CPM are given in among others (Sears, Sears and Clough, 2008) and (Kenley and Seppänen, 2010), chapter 2.

[7] Example: Two activities A and B are to be done in the same area. They can for practical reasons not be done simultaneously, but A could be done before B and B could be done before A.

planning system designed especially for the type of production we find in construction (and shipbuilding).

Graphically a LBMS schedule typically uses flowline (Kenley and Seppänen, 2010, pp. 71), a two dimensional diagram with locations on one axis and time on the other. A good plan is a plan where the lines indicating each trade are continuous (indicating flow of work), not crossing (indicating only one trade at a time in each zone) and with an optimal distance (indicating time buffers).

Summing up, we find that LBMS is specially focusing on the following issues:

1. The different zones where the work is to be done
2. One trade at a time in each zone
3. The trades having continuous work

TAKT PLANNING

As indicated by the name, Takt Planning[8] is focused on establishing a fixed takt in production. Takt Planning is a concept coming from the assembly line in manufacturing, where the takt is the time the intermediate product is at any work station before moving to the next. At the assembly line the takt is a physical reality, the line is moving at a specific speed and all work stations have to comply with this. Not so in construction. Because in construction work is moving through the product, the takt (if there is to be a takt) has to be established by the plan. This is done by dividing the object (e. g. the building or road) into zones and deciding a construction direction in which work is to move. The construction direction is to be established in a way that prevents transportation through zones that can be harmed by such transport or where the transportation can come in conflict with ongoing work, does not mix or intersect ingoing and outgoing material flows, and minimizes the transportation from zone to zone.

The takt time cannot be set shorter than what is allowed by the bottleneck activity (Seppänen, 2014), and sets a common upper-bound on the time anyone trade is afforded to use in any one zone. The plan establishes a push mechanism where all work packages are to be executed at the time and location determined by the takt plan. Due to variability, the trades will have to plan with a certain amount of buffers. If production is lagging behind the plan, the trades will have to work more hours a day than planned or have access to extra workers. (These workers will for obvious reasons have to come from a production process that is not takted.) If the trade is working faster than scheduled, they will either have to reduce their crew size, be idle or have access to a backlog of task. (This backlog will also have to be part of a production that is not takted.) By the end of each takt (time slot) there will be a hand over of every one zone from one trade to the next. The hand over should confirm that all work is done and with the right quality.

Summing up, we find that Takt Planning is specially focusing on:

1. A specific construction direction

[8] We have not found any single in depth presentation of Takt Planning, but have in our work with the paper used Frandson, Berghede and Tommelein (2013), Porsche Consulting (in Press) and Seppänen (2014) as references. Two of the authors have attended a training course in Takt Planning at the Porsche Akademie in 2011.

2. The division of the building (or whatever object is to be constructed) in zones of approximately the same size
3. One trade at a time in any one zone
4. The work to be done within time slots of the same duration
5. Hand over between trades with control of completeness and quality
6. Buffers of tasks and resources

CRITICAL CHAIN (CC)

The motivation of the development of the Critical Chain (Goldratt, 1997) has been in certain shortcomings of CPM, although also many features are inherited from it (Koskela, Stratton and Koskenvesa, 2010). In contrast to CPM, CC acknowledges that there is a need to respond dynamically to uncertain durations. In CPM, the task durations contain buffers to accommodate variation. These buffers inflate the total duration. In CC, the central idea is to explicate these buffers, to situate them strategically and to manage them actively for shortening the duration and expediting the project. This also implies that in a CC master plan, there are no firm task start and end dates. Further, a central idea is that there is effectively only one activity consuming the project buffer at any time – the bottleneck. The assumption is that an improved visibility of buffer consumption creates awareness and opportunity to support the resource concerned and to escalate action when buffer consumption threatens delivery. To make this possible, a frequent reporting, preferably on a daily basis, of projected time to complete the tasks underway is needed.

Summing up, we find that the CC is characterized by the following:

1. Preparation of a master plan that is not assumed to be realized as such
2. Active management of time buffers
3. Frequent reporting of projected task completions
4. Identification of the bottleneck and focusing on supporting and expediting it

AGILE

Agile methods rely on incremental, iterative development cycles in order to complete projects. The aim is to enable adaptation of continuous changes in the development process by adding higher level of flexibility than what is possible with traditional project planning methodologies. Agile methods, such as Scrum[9], are used on projects with a substantial amount of uncertainty in both requirements and technology (Scwaber and Beedle, 2002), e. g. software projects. Scrum deviates starkly from the conventional project management doctrine. There is no work breakdown structure and the dispatching of decisions is totally decentralized (Koskela and Howell, 2002). There is no central representation of action in Scrum. Instead, action follows essentially from the situation, created through prior action and coordination takes place directly among the team members. Feedback cycles are created both on the daily and monthly level (Koskela and Howell, 2002).

[9] The use of the term Scrum is inspired by an analogy put forth by Takeuchi & Nonaka (1986), who compared high-performing, cross-functional teams with the Rugby scrum formation where each team's eight forwards bind together and try to push the opposition eight backwards in order to gain position.

Summing up, we find that Agile is characterized by the following:

1. Incremental, iterative development cycles
2. No work breakdown structure
3. Totally decentralized decision-making and no central representation of action

TASK PLANNING (TP)

While the present paper and the planning approaches described above basically are focused on time scheduling, TP (Junnonen and Seppänen, 2004) has a broader and more holistic approach. In TP the tasks / work packages are planned in detail and considered from six angles: Analyzing potential problems, scheduling, costs, quality requirements and quality assurance, the prerequisites for the task, and ensuring the progress of the task. TP is related to both LBMS and LPS. It uses flowline time scheduling and has a make ready approach similar to what we find in the look-ahead planning in LPS. It does however differ from LPS at one point: While LPS on the detailed level uses week plans, TP planes the single task (or work package) in one entity, disregarding the duration.

Summing up the plan contents focused by Task Planning:

1. A holistic approach, seeing the tasks from six different angles
2. The single task is planned in one entity, unregarding the duration

THE LAST PLANNER SYSTEM (LPS)

Although LPS (Ballard, 2000) is mainly focusing on the planning process, it also has focus on some specific issues regarding plan contents. LPS is a planning system consisting of four or more planning levels[10]. Each planning level has a specific purpose. The criteria of goodness of the plan will therefore be specific for the different planning levels. The first criteria we find on the level of the main and phase schedule. This is to establish a feasible strategic schedule with good sequence of activities. Secondly: In the phase scheduling session the different trades write one task on each post-it note. These tasks should be independent, that is they can be executed without the interference of other trades. The third is that the week schedule should only consist of sound tasks. Sound tasks are tasks with all preconditions for production in place (Koskela, 1999). This is achieved through the look-ahead planning.

Summing up the plan contents focused by LPS we find

1. Good sequence of activities
2. Single craft activities (independent tasks)
3. Sound activities

DISCUSSION

The Transformation – Flow – Value theory of Koskela (2000) sees production as a flow of transformations. The flow is flow in time and space, the transformations are what we in scheduling refer to as tasks or activities. Basically scheduling can

[10] The original version of LPS (Ballard, 2000) has four planning levels. Some later developed versions have extended the number of levels to five and six (Ballard et al. 2009; Veidekke 2014)

therefore be seen as the determination of the connections in time and space between the tasks[11]. In our discussion and the succeeding proposed list of criteria for a good plan, we will use this as our structural approach. First we look at the tasks as such, then we look into their relationship in time and space. A good plan is fit for purpose and is being used. This issue is therefore addressed in a separate section. Both tasks, resources, time and space can be used as buffers, and the plan has to be in compliance with the framework conditions. We will therefore also discuss these two issues in sections of their own, before we present our proposed list of criteria[12].

THE TASKS

An underlying assumption in CPM, LBMS and LPS is that the tasks that will be done are to a very large degree identified and in the plan (that the plan is "complete"). Fireman, Formoso and Isatto (2013) and Leão, Formoso and Isatto (2014) have discovered that this is not necessarily the case. In case studies they find that a substantial amount of the executed tasks and work packages are not in the plan. They call these work packages or tasks informal. The number of informal work packages is highly variable[13] and the reasons are various. Typical reasons can be rework and crews going back to finish unfinished work. Due to these reasons new tasks emerge as the project progresses, and these new tasks are often not included in any plan.[14]

THE USE OF TIME

Bølviken and Kalsaas (2011) find that good flow in time is the combination of two dimensions: A high production volume (intensity / throughput) and a uniform production volume per time unit (uniformity / smoothness / lack of mura). In terms of criteria for a good plan this translates to the right project duration and as steady and smooth levelling of production as possible.

Even though correct logic is an underlying precondition for a plan to be good, Galloway (2005) reports that a substantial share of owners and contractors see logic abuse as a primary disadvantage to CPM scheduling. We therefore agree with Kenley and Seppänen (2010) that correct logic should be an explicit criterion for a good plan.

Should we introduce a takt in the plan? There must be buffers in a takt system coming from production that is not running according to takt. If one is to use Takt

[11] Kenley and Seppänen (2010) divide planning concepts into two groups, activity-based and location-based concepts.

[12] During the review process one of the reviewers made us aware of the fact that Kenley and Seppänen (2010) ask the same question as the title of the present paper and propose a list of criteria as an answer to the question (pp. 202-203). While we approach the issue from the perspective of LPS, they approach it from a LBMS perspective. They do however not present the reasoning behind the structure and contents of their list. We have therefore in our discussions only to a limited degree been able to draw upon their work.

[13] Fireman, Formoso and Isatto (2013) find that the number of informal work packages can reach more than 80 % of the total number of work packages! (An average informal work package will usually be smaller than other work packages.) The case study of Leão, Formoso and Isatto (2014) had an average of 34 % informal work packages.

[14] Another thing is that a share of tasks may be deliberatively left out of the plan. According to Kenley and Seppänen (2010) tasks that can be done flexibly, do not require special skills and do not have a large work content, can be left unscheduled and be used as workable backlog. They say that at least 80 % of the workers hours should be scheduled accurately, but do not give any argument for this specific figure (pp. 217-218).

Planning, the question therefore seems to be which projects or parts of projects should and should not be run with takt[15]. Seppänen (2014) finds that Takt Planning can be applicable in some types of projects, but that it can also be a risky strategy. It is therefore hard to see Takt Planning as a universal plan approach in construction and we will not include takt as a criterion in our proposed list.

THE USE OF SPACE

In manufacturing the intermediate product is moving through production. The utilization of space is therefore handled in the planning of the factory layout and not in the everyday planning of production. In construction production is moving through the product. The utilization of space is therefore changing continuously and has to be taken care of through the planning. In contrast to the other planning systems LBMS and Takt Planning are focusing explicitly on space as a constraint and a production resource.

FIT FOR PURPOSE

One of the basic principles of LPS is according to Ballard, Hammond and Nickerson (2009) to plan in greater detail as you get closer to doing the work. Although this principle is obviously common sense, CPM is not in compliance with it. CPM assumes that it is both possible and desirable to plan in great detail long in advance. As we see it, this assumption is based on an underlying understanding of construction as a more stable and predictable process than what it actually is. On the other hand Agile is developed to comply with projects that are less predictable and can have more adjustable goals than what we usually find in construction. Generally speaking, the plan should have a level of detail that is consistent with the level of variability in the project and the level of detail should increase the closer to execution one gets.

Any plan system will have (at least) two principal plan levels: A strategic top level (typically a main/master or phase schedule) and an operational detailed level (typically a week or day schedule). In LPS the interconnection between these two levels is established through a separate plan level, the look-ahead plan. A main focus in CPM is the main schedule and the break down of this in a work breakdown structure. The weekly plan is made simply by making an extract of the work breakdown structure. This creates a push mechanism from the main to the week schedule. Moving on to Agile we find a highly decentralized work process and no plan structure as such. What we find instead is a product backlog replacing the main schedule, control meetings after each Sprint replacing the look-ahead process of LPS and daily Scrum meetings replacing the week plans of CPM and LPS. This constitutes a focus of Agile totally opposite that of CPM with LPS somewhat in between. In Agile the main focus is on daily Scrum meetings and continuous flexible short term planning. The goal of the project is represented by the product backlog, but can also be changed as the project proceeds.

LPS was developed through a critique of CPM. An important goals with LPS was to create a make ready process securing that the tasks on the week plan can really be completed (are sound). This is achieved through the constraint analyses and the look-

[15] The case study by Frandson, Berghede and Tommelein (2013) describes Takt Planning used in a limited part of a project.

ahead plan. The look-ahead plan of LPS is a totally new construct compared to CPM and can be seen as a main strategic focus of LPS. Compared to CPM and Agile, LPS has a balanced focus both on the high and low levels of planning.

A project manager once said to one of the authors: "I plan to tell others what I think". The term planning often refers to several activities: Analysis, decisions, documentation, communication, follow up and control. An important element in these activities is obviously communication internally in the group doing the planning and externally to parties that have not been involved in the planning. The plan should therefore have a structure and layout with intuitive and visual qualities making it easy to understand and use. What these qualities are will depend on by whom the plan is to be used.

THE LEVEL OF BUFFERS

Buffers are waste. When buffering, specific types of waste (the buffers) are deliberatively introduced into the production system in order to establish a satisfactory level of flow and thereby reduce the total amount of waste in the system. There are buffers in all real life production systems, the point is to reduce them to the minimum necessary to maintain a level flow (Bølviken, Rooke and Koskela, 2014). Buffers can be found both inside the project (e. g. a backlog of tasks ready for execution) and outside (e. g. resources that can be called for). Both tasks, resources, time and space can be used as buffers. Flexibility can be seen as a precondition for the availability of the buffers, but can also be seen as a buffer itself.

The amount of buffers needed in a production system will be a function of the variability of the system: the higher the variability, the higher amount of buffers is needed. Because the variability of the construction process is normally high, it can be of critical importance to have the optimal level of buffers in the plan (not too high, not too low).

COMPLIANCE WITH THE FRAMEWORK CONDITIONS

All projects will rely on explicit and implicit, internal and external framework conditions. This can be the availability of resources, time frames, physical boundaries, costs, contractual risk, etc. (see the description of Task Planning). A good plan should make important external and internal framework conditions explicit and thereby make it possible to have them under surveillance.

CONCLUSION – CRITERIA FOR A GOOD PLAN

Based on the presented plan concepts and the discussion above, we propose the list of criteria presented in Table 1. It also indicates which criteria are inspired by which of the discussed planning concepts and which are mainly based on the discussion in the present paper.

The next step in our work with the topic of this paper will be to test the use of the proposed list in projects using LPS. The goal of this testing will be to find out if the list will turn out to be useful and how the use of the list could be integrated into the LPS planning process.

Table 1: Proposed criteria for a good plan

	Critical Path	Location Based	Takt Planning	Critical Chain	Agile	Task Planning	Last Planner	Present paper
The tasks								
1. All major and important tasks are in the plan								x
2. Independent tasks only (ideally)		x	x				x	
3. Sound tasks only (in short term plans)							x	
4. The preconditions for the tasks to become sound are identified (in long term plans)						x	x	
5. Identified bottlenecks			x	x				
6. Resources are available						x	x	
7. Suitable level of task and resource buffers			x				x	
The use of time								
1. Right sequence and correct logic	x	x	x			x	x	
2. The trades have continuous work (ideally)		x					x	
3. Suitable level of duration tightness and time buffers	x	x		x				
4. Duration is in compliance with the framework conditions	x	x	x				x	
The use of space								
1. A good division in zones		x	x					
2. Suitable construction direction		x	x					
3. One trade at a time in each zone (ideally)		x	x					
4. The use of space is in compliance with the framework conditions								x
5. Suitable level of space buffers		x						
Fit for purpose								
1. Suitable level of detail					x	x	x	
2. Good visual presentation		x						
3. Good intuitive quality								x
4. In compliance with contractual demands	x							

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PULL VS. PUSH IN CONSTRUCTION WORK INFORMED BY LAST PLANNER

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ABSTRACT

The Last Planner System (LPS) is widely characterized as a pull system. In this paper the authors question if this characterization is correct. The authors argue that LPS applies a combination of pull scheduling and push control at the shop floor level. Line of balance and Takt-time Planning are also discussed. There are no findings that support that these techniques applied in combination with LPS change the authors' main conclusion.

The goal of this paper is to provide a better understanding of LPS and to contribute to the discussion of pull-push. The authors agree that pull may not always be the best option. The authors argue that choosing pull, push or a combination of the principles should be based on the production dynamic in question.

KEYWORDS

Pull & push, Last Planner System (LPS), Line of Balance, Location-based management systems (LBMS), Takt-time planning (TTP).

INTRODUCTION

The Last Planner System was developed in 1992 by the Lean Construction Institute (LCI) (Ballard, 1993). LCI presents LPS as a production system created to produce predictable work flow and fast learning in programming, projecting, construction, performance documentation and the handover of projects[4]. LPS and lean construction was developed in the wake of lean, inspired by Toyota, which first was developed for manufacturing (Ballard, 2000; Kalsaas, Grindheim and Læknes, 2014).

Pull as a production logistical principle is central to lean manufacturing and production (Womack and Jones, 1996; Rother and Shook, 1998). It is often associated with just-in-time production, a commonly used term previous to when the term «lean» was introduced (Kalsaas, 1995). A search in the IGLC (http://www.iglc.net/) conference papers, using the keyword "pull" yielded 63 matches[5]. The query «pull scheduling» returned 2 matches.

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[4] Based on a undated note downloaded from LCI's home page, 2014

[5] The database includes papers from the 4th annual conference to the 22th in 2014

Ballard (2000) defines «pull» in production control, by referring to Hopp and Spearman's (1996) definition for manufacturing: "Pull systems release materials or information into a system based on the state of the system (the amount of work in process, the quality of available assignments etc.) in addition to due dates". In contrast, the push system releases materials or information into the system "based on preassigned due dates" only. Work controlled by push is based on a plan. Ballard then refines pull in construction to be "ultimately derivative from target completion dates, which specifically applies to the internal customer of each process". Arguments on pull are emphasized as part of the Lookahead-plan (pulling work from upstream production units). Ballard argues that the constraint analysis in the Lookahead-plan is utilizing a pull-mechanism, in contrast to traditional construction scheduling (e.g. the Critical Path Method -CPM) which is based on push-mechanisms. The Lookahead-plan supports Ballards claim that LPS is a pull system: "Further, making assignments ready in the Lookahead process is explicitly an application of pull techniques. Consequently, Last Planner is a type of pull system." Koskela (1999) also emphasizes the pull system as an important instrument for "ensuring that all the prerequisites are available for the assignments» as a part of the Lookahead-plan in his design criteria for production systems. Thus, the pull-mechanism is justified by the criteria that upcoming assignments are actively prepared. Kalsaas, Grindheim and Læknes (2014) considers "pull" to be one of the basic principles of LPS.

Pull-mechanisms do not seem to be support production plans involving direct construction work (shop floor level). Ballard (2000) claims that concrete delivery to a construction site is one of few shop floor level activities which is traditionally governed by pull mechanisms. This is due to the short shelf life of fresh concrete, which makes it necessary to commission it only when it is actually needed at the construction site. Long supplier lead-time for most materials and products is suggested as the reason for the domination of push-mechanisms on the shop floor level. In his doctoral work, Ballard (2000) calls for a "puller" to be included in LPS on the action item log. He is, however, not specific about what that should be.

This paper questions whether LPS is a pure pull system. The authors theorize that this is not the case, and that clearer and more precise use of terminology is necessary in this area.

This paper gives an overview over what is considered push and pull in a production logistical environment. Pull is then considered in the context of the Toyota production system. This is used as a reference for further discussion subsequently followed by a description of LPS. LPS in turn is analyzed in relation to pull and push. Lastly, the relationship between push, pull, milestone planning, LBMS, Line-of Balance and takt-time planning is discussed.

WHAT IS PULL AND PUSH?

A pull signal is dispatched when a product is procured. In construction we often deal with Engineer-to-order, and despite of the customers pull, the production might be pushed toward the contracted delivery date. In the context of this paper, pull is defined a downstream work process that pulls materials from an upstream process. This mechanism enables the amount of work in process to be reduced, when compared to the push control mechanism. Push is closely tied to Material Requirement Planning (MRP), where production schedules for each work station in a production chain are developed centrally. There are some disadvantages for this system. If problems occur in a work station downstream in the chain, work in process will build up in front of the workstation with unexpected downtime. A pull mechanism, on the other hand, reduces the demand for material from the upstream workstation, since it only produces materials according to demand. This dynamic propagates further upstream in the production chain.

One renowned pull system is known as kanban. Kanban is the Japanese word for “signboard”. Kanban cards are used as a method for issuing commands in the production of material. The kanban system was developed by the Toyota Motor Company, and it is connected to JIT production and pull. Kanban can be described as a control system for replenishing material based on actual demand. The demand can be from an external customer or from a downstream work process. The kanban system is based on the creation of buffers along the production line, which replenishes materials simultaneously with their consumption. The demand from the customer is visualized upstream in the production chain through kanban cards and kanban billboards. This provides clear management information which facilitates operator’s ability to prioritize the orders. Kanban is therefore known as a systematic method for material and information determination on the shop floor level. Designing and scaling a kanban system requires both analysis and planning. The focus of the design stage is to locate buffers and kanban loops, while scaling is focused on determining the number of kanban cards to circulate between the producer and consumer of a specific unit in a kanban loop. The number of cards is calculated from demand forecasts, assumed lead times, and the tolerances for the required security factor needed to compensate for demand variations.

The number of kanban cards (N) in a loop in its simplest form can be calculated in the following way: $N = E*L/C$, where E = demand in a defined interval, L = lead time from delivery of a kanban order to recipients, C = unit load. If $E = 150$ pieces per day, $L = 2$ days, $C = 40$ pieces, the loop would need 8 kanban cards. Kanban will increase the amount of material which is in process during unstable demand and lead times, e.g. when operational time for production equipment varies.

A selection of literature for production logistics, argues that the material and production control system should be based on a variety of characteristics of the production line (Hyer and Wemmerlöv, 2002; Kalsaas and Alfsen, 2009). The literature suggests that it is beneficial to use pull solutions when the following criteria are met: Low variation of demand; Short changeover time; Small batch size; Small transport batches; Simple flow patterns; Balanced bottlenecks; High levels of operational equipment time; High degree of work flexibility; High delivery reliability; High production quality; and High supplier performance;

Push solution is recommended for the opposite values of these variables. One implication of this theory is that pull solutions may not always be optimal independent production technologies if there is stability in the value chain. Ballard (1999) takes an open stand on pull-push when it comes to design management: “…it may well be true that pull techniques are inapplicable to design management. But it is clear that their absence results in considerable waste and inefficiency”. There are subsequently several approaches of combining push-pull in production control, such as the methods described by Huang and Kuisak (1998).

TOYOTA'S PULL PRODUCTION SYSTEM

Toyota's car manufacturing is done on an assembly line (Kalsaas, 1995). The value chain typically consists of three factories: chassis, painting and assembly. Cars are often painted in batches using the same color in order to reduce changeover time. Each work shift has a production goal set for them for a given number of cars. The production goals as well as the numbers displaying the current status in real time are showed on a luminous billboard visible from the assembly line. All the cars in production are presold. The buyers are generally car dealerships/dealers or end users. The day-to-day production is based on an executive plan. When a painted chassis enters the assembly band and moves from work station to work station, the product gradually becomes a car. The majority of the car parts are assembled by a number av work stations. The parts are pulled to each work station based on a kanban system with a loop to the subcontractors. The subcontractors are usually located close to the car factories in the form of production facilities and/or storage. When a loading unit (kanban) is empty for parts, production is moved to a new loading unit. The released kanban card from the empty kanban-container is then posted on a billboard. This card is used a production order/delivery order to a subcontractor or internal supplier, who is responsible for collecting the cards and refreshing the supplies accordingly.

The assembly line in this respect can strictly speaking be considered a push system. This is because there is no demand from the downstream workstation that initiates work. The belt moves the car frame using a calculated and balanced speed from workstation to workstation for assembly of parts, components and systems.

Toyota, in addition to this process, also employs a quality control system to assure that all the components are correctly assembled before being delivered to the next work station. This process is used to avoid pushing a product that is not ready to the following workstation (Kalsaas, 1995). If an operator experiences difficulties with his assembly, a string is pulled which signals a senior operator. If the operator and the senior operator are not able to solve the problem within the tolerances av predetermined time buffer, the whole assembly line comes to a halt. The system assures supply of products with correct quality before they proceed downstream.

LAST PLANNER[6] SYSTEM

Ballard, Hammond and Nickerson (2010) derived five principles from LPS: Plan in greater detail as you get closer to doing the work; Produce plan collaboratively with those who will do the work; Reveal and remove constraints on planned tasks as a team; Make and secure reliable promises; and Learn from breakdowns.

Kalsaas, Grindheim and Læknes (2014) however conceptualized six underlying principles from LPS, one of which is to "employ the pull principle as the foundation for production control".

The first objective of LPS is to identify what **should** be done via Master Scheduling and Reverse Phase Scheduling (RPS) (Ballard and Howell, 2003). The Master Schedule identifies the milestones for the project, and the focus in the RPS meetings is to pull work packages to meet the milestones thereby validating the schedule. RPS also identifies the work required in order to release work to other

6 Trademark of Lean Construction Institute

trades and teams. The second objective of LPS is to redefine the work that **should** be done into work that **can** be done by removing identified constraints in the make ready process. Ballard and Howell (2003) identified three categories of constraints for tasks:

Directives (e.g. design documents, specifications, task assignments); Prerequisite work (work that must be finished before the activity starts); Resources (labour, equipment, space)

Koskela (1999) has identified seven similar pre-conditions to any construction work: design, components, materials, workers, space, connecting work and external conditions. These seven prerequisites are also identified as the seven flows. Work is prepared by creating a lookahead schedule for the upcoming 4-6 weeks.

The final planning objective is to commit to work that **will** be done in a commitment meeting which addresses the work plan for the upcoming week. The Last Planner, the individual who will be in the field directly managing or performing the work, commits to complete the assignment. Quality assignments should meet five criteria: definition, size; sequence, soundness and learning (Frandson, Berghede and Tommelein, 2014). In conclusion, LPS identifies what work **should**, **can** and **will** be done and lastly what was actually **done**.

ANALYZING LPS IN RELATION TO PULL – PUSH

The master plan in LPS is an executive plan made up of milestones, and contains no pull mechanisms. The one possible exception to this rule is that some milestones are adjusted or identified based on the RPS-process, where the end of a phase normally is a gate defined as a milestone. RPS itself can be interpreted as pull scheduling as the necessary work for an addressed work package is determined in the method. However, RPS incorporates planning on a more strategic level, not in production control at shop floor level.

A central aspect of the lookahead schedule is to make work packages systematically sound. This is done by removing constrains, i.e. by making materials and equipment available, completing drawings, gathering necessary information and staffing accordingly. Furthermore it enables accessibility to the work place and makes sure that previous tasks are completed with the specified quality indicators. In the weekly work plan (2-3 weeks), work packages are further detailed and specified while constraints and rescheduling are continuously addressed towards execution. The LPS method is based on getting the production done according to plan (Kalsaas, Grindheim and Læknes, 2014). In some implementations, LPS will be supplemented with short daily morning meetings to make the latest adjustments, as unforeseen events always can occur.

By comparing LPS with Toyota’s method of controlling car assembly on the shop floor it is quite obvious to the authors that LPS strives to replicate the same mechanisms. Specifically the make ready process in lookahead-scheduling is similar to Toyotas procedures which only allow a partially assembled car to pass down the line when upstream work is step by step quality controlled. The make ready process in LPS is also conducted on a more detailed level in the weekly work plan. It is also possible to halt the work if all prerequisites to complete a work package are not sound. However with LPS, work from a backlog of sound buffer work packages can be included. It is the authors’ understanding that halting work completely rarely occurs in construction projects using LPS, like it does in Toyota’s case. However, work in an

LPS system might be rescheduled in the lookahead-process and/or in the weekly work plan, when necessary.

Pull scheduling is obvious an attribute of LPS, but it is more difficult to identify pull-mechanisms in production control at the shop floor level. A crucial question in this regard is whether the make ready process in LPS represents a pull mechanism. The authors do not believe this to be true. In the make ready process the constraints are removed in order to make the plan achievable. This principle is quite similar to the process in CPM where effort is increased to remove constraints and rescheduling is done as needed. A specific difference between the two is the possibility of halting production in LPS. However, halting production from upstream to downstream, no matter how efficient, is not considered a pull mechanism.

Toyotas method for car assembly cannot be characterized as pure pull production, since the assembly line is ”pushed” out from a predefined takt and speed customized for each work station. Toyota does still have a pull system that pulls the components to the assembly line, and a system build around the assembly line to ensure that work is delivered with the correct quality to a process downstream. In conclusion, Toyota combines pull and push production in their control of car assembly.

If construction projects are to achieve the same level of pull in production as Toyota’s system for car assembly, it is necessary for the different components in the seven flows to be established and pulled to production, e.g.: Drawings, equipment and materials, staffing, the work place. Establishing pull on drawing, equipment and materials are manageable, and there are examples of this being done e.g. vendor managed inventory controlled by min/max levels and cargo terminals which deliver small batches of bulky material. Terminals are used as buffer storages outside the construction site, which facilitates optimal material availability. This is set up according to the optimal delivery schedule for the supplier and the main contractor (economy of scale in transportation and order size). The construction sites can pull material from the terminal to the construction site as needed. Since the goods can be both confirmed to be correct and the quality can be controlled on the terminals, the construction sites can manage to have a tight and precise delivery, and avoid excessive stock at the construction site. The degree of on time delivery seems to increase with the use of terminal supply systems in construction[7].

When it comes to a resource plan for labour, the plan resembles a push based plan just like any other MRP plan. It is difficult to see how it is possible to achieve a pull-mechanism for labour when the workers’ interests must also be accounted for. By applying work buffers, increased flexibility can be achieved for labour demands.

MILESTONES AND PULL – PUSH

The master plan in LPS is a milestone plan, which often is part of the contract between a professional client and the main contractor in Design-Bid-Build. “Construction of exterior skin” is a commonly applied milestone which differentiates between the finish of exterior and start of interior work in construction.

The focus of the RPS meetings is to pull the plan to the milestones in order to validate the schedule (Frandson, Berghede and Tommelein, 2014). The challenges

[7] Experiences from Skanska Norway

that emerge from the use of the RPS process are commonly associated with the need to make changes in regards to the "exterior skin" milestone. This is necessary to enable a production process characterized by effective utilization of resources within the time available. This challenge has been experienced first-hand by a large Scandinavian contractor. This contractor usually starts a project by organizing the RPS process, not only for the intermediate milestones, but for the entire project. The challenge arises when the date of the milestones cannot be changed in the contract, which most likely stems from a lack of trust. This lack of trust can be explained by the terms asymmetric information and opportunistic behaviour in the transaction cost theory (Williamson, 1975). An Integrated Project Delivery (IPD) contract is likely to provide improved conditions for collaboration when it comes to trust and establishing milestones.

However, whether a milestone is determined in a collaborative RPS process or is strictly a bureaucratic decision becomes inconsequential in regards to shop floor control. The determination of a milestone can be described as a point in time where the building project is expected to have reached a state or degree of completion. The work itself might be pushed towards this point. As a result of this the production level is associated with how the work progress is controlled on the shop floor, as explained earlier in the paper.

However, it seems unfavorable that central milestones applied by different disciplines and trades are decided without collaborative planning (RPS) and joint understanding of processes and methods. Functional milestones pre-established solely with the client could enhance the workers sense of being pushed in a way that is not resource friendly or appropriate.

LOCATION BASED MANAGEMENT, TAKT-TIME PLANNING AND PULL VS. PUSH

The location based management system (LBMS) (Kenley and Seppänen, 2010; Kala, Mouflard and Seppänen, 2012) for construction and takt-time planning (Frandson, Berghede and Tommlein, 2013; Linnik, Berghede and Ballard, 2013; Yassine et al., 2014) is frequently combined with LPS (Seppänen, Ballard and Pesonen, 2010; Frandson, Berghede and Tommlein, 2014). In this section the authors discuss if location based management and/or takt-time planning can affect the author's previous conclusions about LPS.

LBMS (Seppänen, 2014) is related to both Line-of-Balance (LoB) (Lumsden, 1968) and the flowline technique (Mohr, 1979). LoB addresses repetitive work, while flowline technique removes that constraint and uses location rather than quantity of elements. LoB does not consider flexible location breakdown structures. In his LBMS development, Seppänen (2014) also refers to Arditi, Sikangwan and Tokdemir's (2002) integration of LoB, CPM and Russell and Wong's RepCon (1993). The main contribution of LBMS is the use of a flexible location breakdown structure. It combines a CPM algorithm to a location based technique through layered logic and a cost and risk model which accounts for workflow continuity. It also adds buffers between locations, and a production control system which forecasts future progress based on past production rates (Kenley and Seppänen, 2010).

Takt-time is originally a lean manufacturing concept. The focus of this concept is to enable all work operations and processes to generate a product that is synchronized with the customer’s demands and requirements while staying within the available work time (Rother and Shook, 1998). When applied to construction, takt-time has been defined as the maximum number of days allowed to complete work in each location (Frandson, Berghede and Tommelein, 2013).

According to Linnik, Berghede and Ballard (2013) the priority of LBMS is to maintain labor utilization. The priority of the takt-time is to have work flowing continuously. Both systems will in ideal situations eliminate downtime for both the staff and the line. LBMS allows the duration of a task to vary when the quantities are different between locations, while takt-time requires task duration to be the same. Tolerances allow for corrective actions in LBMS (Seppänen, 2009). The takt-time is calculated based on the production rate of the bottle neck task or project requirements. A challenge in the takt-time approach is the risking loss of capacity for faster tracks following the bottleneck trade.

The purpose of LBMS is to organize production in production lines. Usually procedures are performed in order to run the production lines parallel, since this reduces the time required for construction. Parallel lines can be accomplished by moving production between different production lines, splitting lines that appear to be too long, and combining lines that seem to be too short. In addition, adjustments related to available personnel, production equipment and the share of prefabricated materials etc. can be made. In some instances it is possible to decrease construction time by reducing a selected discipline`s workforce.

In the context of LoB the authors are trying to conceptualize that the pull signal actually comes from the zone/control area, e.g. special rooms or floors. The signal shoes that the preceding trades have finished up their work in the zone, and as a result the subsequent disciplines can begin their activities. It is necessary to conduct an educated estimate in advance av operations to determine the timeframe a discipline needs to conduct their operations in the relevant zone. If there are possible uncertainties in determining lead time, a time buffer should be added to mitigate any risks. It is unrealistic to assume that subsequent disciplines would be on stand-by and ready to move into the control area regardless of when it is ready. It is common practice for certain disciplines to work in different control areas dictated by the project schedule. This means that there is no true pull mechanism present for production at the shop floor level, even though one can argue that the planning is pull based.

In takt-time planning the takt time is decided by a central decision maker on behalf of all trades, which can be regarded as the customer. However, as with LBMS, the implementation of production appears to be pushed based, as the production train runs its pace based on pre-calculated durations, and not because of pull signals issued based on the state of the object in a specific location. It is apparent that the “will do” mechanism in LPS is violated in takt-time planning.

CONCLUSION

It is necessary to distinguish between different levels in production when deciding which mechanisms of pull and push should be applied to the organization of construction projects. The first level can be described as shop floor control. This deals with how production orders are issued and gives input to "how much of what" should be produced at a workstation. In practice, this can be done by using kanban cards (pull) or by using a centrally calculated production schedule (push) for each workstation in the value chain. The second level can be described as strategic planning. In a kanban system there needs to be a strategic planning phase to identify the required number of kanban cards. The master plan, RPS and lookahead scheduling are all part of strategic planning in LPS.

It is obvious that LPS covers pull scheduling, but the paper argues that production control at the shop floor level is basically push based without any pull mechanism on the work plan level. However useful, the make ready process is push based, even though it can be argued that it can be used to halt production.

Toyota's control of car assembly is also a combination of pull (materials to the line) and push (the moving belt). This indicates that LPS needs to be able to pull materials, equipment, drawings etc. to production to achieve a level of pull control as seen with Toyota. In this paper the authors have also discussed if a combination of LBMS and LPS, or takt-time planning and LPS, would change the conclusion. The result is that both approaches are also comprised of predefined schedules to direct work based on zones/control areas. This means that none of these options represent a pull based system. It is not sufficient to simply remove constraints in order for work to flow in and between disciplines.

The authors believe there is a need for a more nuanced and critical overview of how the term is used. LPS, LBMS and takt-time planning do not automatically become inferior for not applying pure pull concepts. Pull is therefore not necessarily the best technique for organizing production logistics at the shop floor level.

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A PRODUCTION CONTROL TOOL FOR COORDINATION OF TEAMS, MEETINGS AND MANAGERIAL PROCESSES

Omar Zegarra[1] and Luis Fernando Alarcón[2]

ABSTRACT

During construction projects, the productive deployment of operations depends on the reliable supply of the production control function, where the proper coordination of teams, meetings and managerial processes is crucial for performance. Currently the use of the Last Planner System for providing this function has been successful; despite the importance it claims in the social domain, it does not explicitly regulate the coordination of teams and meetings with the managerial processes. In order to address this gap, we developed a prototype tool, based on a Multi- Domain Matrix, for handling and tracking the performance of these elements.

This paper introduces the *Matrix of Interacting Groups*, which evaluates the interaction of teams, meetings and managerial processes during the production control function supply. It was initially tested in a Chilean housing project and it allows the identification of team members, meetings, processes, and provides insight into the system key properties. It enables a comprehensive description of the production control function and generates a framework for tracking and for potentially fine tuning it. Although the tool is still under development, it seems promissory for providing a high level and practical regulation of production control.

KEYWORDS

Production Planning, Control, Complexity, Design Structure Matrix, Coordination

INTRODUCTION

During the execution of construction projects, the production planning and control function (PCF) is the bottleneck of performance. It precedes and regulates the deployment of operations. Ideally, the PCF supply could be depicted as a sequence of managerial processes that emerge from the interaction of functional, social and technical elements in order to meet project demands through the generation of reliable outcomes (Zegarra and Alarcón, In press). In this view, the social agents are the key action triggers; they perceive the environment's incoming stimuli and then react in order to respond to them (Winograd, 1987; Heylighen and Vidal, 2007).

Currently a successful tool for PCF supply is the Last Planner System (LPS). Its

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use up to now has generated many positive outcomes (Fernandez-Solis et al., 2013). The Last Planner System (Ballard and Howell, 1998) emphasizes a proactive and progressive solution of project goals using an arrangement of managerial processes and meetings driven by an empowered team. The proper LPS use is evaluated mainly by the percentage of plan completed (PPC) and its effects on operations.

Despite the importance the LPS puts on the relationship between teams, meetings and managerial processes, these elements lack an explicit mechanism to depict and regulate their proper joint work. The LPS emphasizes and details the arrangement of various managerial processes and meetings, and although the need for empowering the team is clearly mentioned, it does not provide a view about how these elements fit together with the project's social network (Priven and Sacks, 2013).

There is a lack of explicit regulation of the elements upstream of the managerial processes of the PCF supply; this gap has the potential to impact the PCF performance. The value provided by a system is driven by its architecture (Eppinger and Browning, 2012). The variability propagation over this causal structure affects its performance and the PCF supply is not the exception (Zegarra and Alarcón, 2013).

In order to address this issue, this work introduces a prototype tool entitled Matrix of Interacting Groups (MIG). It aims to analyze and manage the interaction of team members, meetings and managerial processes over the PCF supply structure. The tool considers the PCF as a complex system and uses a special type of Design Structure Matrix as the basis for analysis and the LPS to describe managerial processes used.

This work addresses the background, then the MIG features, next the method, results & analysis of the pilot case used to test the tool and finally a discussion.

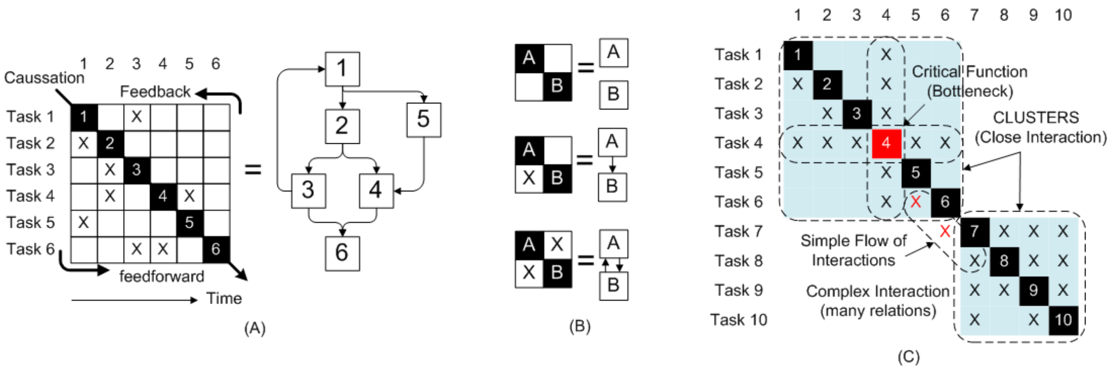

Figure 1: Design Structure Matrix (DSM). (A) & (B) adapted from Eppinger & Browning 2012, (C) Structural Features Adapted from Lano (1977*)*

BACKGROUND

DESIGN STRUCTURE MATRIX (DSM) (LANO, 1977)

The DSM "*is a simple tool to perform both the analysis and the management of complex systems. It enables the user to model, visualize, and analyze the dependencies among the entities of any system and derive suggestions for the improvement or synthesis …*" (Lindemann, 2015). This tool is a square NxN matrix (Figure 1A) that describes the system's elements and their relationships; its key benefit is its graphical layout which enables an easy and useful representation of the system architecture (Eppinger and Browning, 2012; Lindemann, 2015).

The DSM depicts causal dependences between elements within one domain. The included elements are depicted as headers of rows and columns as well as over the matrix diagonal line. The "X" marks represent links between elements, where a column of marks depicts the outputs generated by an element; a row of marks depicts the inputs received. The diagonal lineal also depicts the causal organization of elements over time so the marks below & above the diagonal may depict feedforward (FF) & feedback (FB) interactions respectively (Lindemann, 2015). In Figure 1A, the DSM depicts the arrangement of six tasks and an equivalent graph for the same six tasks (where the elements are depicted by nodes and each edge between two nodes depicts a relationship). The feedback relationships, such as 3 to 1 and 5 to 4, are depicted by the marks above the diagonal line in the locations (1, 3) and (5, 4). The other relationships are depicted below the diagonal; e.g. 1 to 2 is depicted in (1, 2).

The DSM display reveals the system structural configuration and provides clues for its management. It includes three basic relations as shown in Figure 1B: parallel (no links, and elements do not interact), sequential (one link, with the effect of one element on another) and finally coupled (two links, showing an intertwined relationship). The combination of these arise as a structure that allows us to identify key structural features (figure 1C), e.g. bottlenecks, clusters, etc., the handling of these features can improve the system's behavior (Lano, 1977; Lindemann, 2015).

The links depict non-deterministic causal relations in the system. Grossly depicted by processes or probabilities (Schaffer, 2011), these links drive the emergence of features and value (Eppinger and Browning, 2012), and their management, depicts the coordination effort over the system (Malone and Crowston, 1994).

One special type of DSM is the Multiple Domain Matrix (MDM). It enables a system multi-domain representation. An MDM layout depicts various related DSMs (each DSM depicts a different domain), all in a single matrix. The relationship between two DSM matrixes, e.g. [A] & [B], is depicted by rectangular matrices which reveal the correspondence of [A] & [B] elements. The rectangular matrices, according to their location above or below the diagonal, can be labelled as feedforward or feedback respectively (Lindemann, 2015).

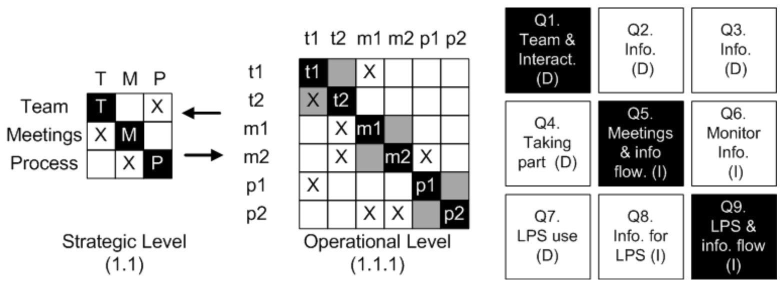

Figure 2.Matrix of Interacting Groups (MIG): (A) Architecture & (B) Interactions

MATRIX OF INTERACTING GROUPS (MIG)

DESIGN: CONCEPT & DEFINITIONS

The Matrix of Interacting Groups (MIG) is a tool for the analysis and management of the PCF. The goal of MIG is to enable a high level analysis and management of the social and process domains of the PCF. This tool is complementary to methodologies which provide an operational platform for executing the PCF supply (Zegarra, 2012).

The tool includes two interacting matrices which depict operational and strategic views of the PCF. Each matrix encompasses three categories of elements: *Teams*, *Meetings*, and *Managerial Process*. The operational matrix is a low level description of the interaction between project team members, meetings and the managerial process used. The strategic matrix is a high level description of the interaction between sub-teams, meetings types and managerial process types. The strategic matrix is built based on the operational matrix and then the strategic matrix status provides feedback to the operational matrix driving changes on it. These matrices and their interacting elements depict a hierarchical multi-domain organization of the PCF supply which is evaluated over time based on the matrices' features (Figure 2A).

The Team category depicts the human agents involved in the PCF and it includes two levels: Sub-teams (1.1) and Individuals (1.1.1). Level 1.1 depicts functional groups, e.g. safety, and level 1.1.1 indicates occupations, e.g. project manager.

The Meetings category depicts the meetings held over the duration of the project and it includes two levels: Meetings Type (1.1) & Meetings (1.1.1). These levels depict categories according to the managerial process they helped to run; for example, planning meetings (type) or weekly meeting (meeting).

The Managerial Process category depicts the PCF supply processes and it includes two levels: Processes Types (1.1) & Processes (1.1.1). These levels depict, respectively, the processes grouped by categories for example plan type and the specific managerial processes used over the project, such as the LPS lookahead.

The interactions depict the dependences between elements. The MIG interactions are represented using language since they depict a communication/action process, specifically conversations (Winograd, 1987). In some cases these links depict communication acts, i.e. face to face utterances or flows of information (meaningful data) and in others only actions i.e. situated data (environmental information) perceived by the human agents (Heylighen and Vidal, 2007). In a previous and related study, a method to measure the flow of formalized conversations over the PCF supply was tested (Zegarra and Alarcon, 2013). This research completes that study by assessing the non-recorded conversations which support the flow of formal conversations and that relate them to the meetings and the social network of the PCF.

CONSTRUCTION OF MATRICES

Matrix Structuring

Figure 2B and Table 1 depict the matrices' structure and elements. Quadrants Q1, Q5 & Q9 depict the elements and interactions from teams, meetings and managerial process. Then Q4, Q7 & Q6 (feedforward) and Q2, Q3 & Q6 (feedback) depict dependences between these. Also, Figure 2B depicts the attribute used to represent each interaction and indicates if the data is collected in a direct (D) or indirect way (I).

Data

The direct data is collected using a field survey and the indirect data is calculated using direct data. The direct data depict measured links; for example, the Q4 interactions are obtained by directly by asking the team. If the direct evaluation is complicated to obtain, then, the data about the link is calculated based on pertinent and available links; for example, in Q5 it is hard to directly assess the information flows between meetings, hence the Q5 links are calculated using Q4 & Q2 data (for feedforward and feedback links respectively). Q4 includes information about all the persons who attended the different meetings; the weighting of this information provides a way to depict the meetings´ links (Wasserman and Faust, 1994).

Table 1: MIG Elements

Category	Level 1.1 (Strategic)	Level 1.1.1 (Operational)
Team	*Sub Team:* Management (MGMT), Tech. Office (OT), Administration (ADM), Safety (PdR), Production (PROD), Sub Contract (SC).	*Members:* Site Manager, OT Chief, OT Eng., Accountant, Safety Eng., Warehouseman, Superintendent, Foreman, Sub Contractor
Meeting	*Meeting type*: Plan, Get, Set, Do, Ctrl	*Meetings:* LPS Weekly Coordination Meeting, Daily Instructions, etc.
Process	*Sub processes type*: Plan, Get, Set, Do, Ctrl	*Sub processes*: LPS Weekly Scheduling, etc.

Data Collection

The Instrument for data collection is a field survey. It included 16 closed questions about the outputs & inputs for each element of the matrix. The team questions ask about outputs generated and inputs received by members. The meetings questions ask about attendance, duration, times per week and perceived utility of meetings. Finally, the managerial process questions ask about the use of LPS elements.

Matrix Building

The Matrix building involves arranging the data into the matrix display. This process was executed using an MS Excel Dynamic Table. The building process includes:

Step 01: The collected data is arranged and transformed into data for the matrices. The output from this step is the calculation of the relative importance of the dependences obtained by direct evaluation.

Step 02: The data is arranged into the square N x N Operational Matrix display. The information from surveys constitutes direct data for quadrants Q1, Q2, Q3, Q4 & Q7. Then the indirect data were calculated using the following considerations: Q5=f (Q2, Q4), Q8 =f (Q4, Q7), Q6=f (Q2, Q3) and Q9=f (Q7 Q8, Q3 & Q6). The logic for assessing these indirect links has been the use of direct relationships which could help to build a plausible indication about the indirect links’ configuration. For example, for Q5, a person’s traffic between meetings (Q4) is used as an indicator of the proactive information flows between meetings, and the feedback received by the team after meetings is used to describe the feedback of information flows between meetings.

Step 03: The Strategic Matrix is calculated using the data from the Operational Matrix. The level 1.1 (sub teams, meetings & processes) are used as adding categories.

Indexes

The evaluation of the MIG structure depicts the importance of its elements and their interactions. Currently it is based only on the use of the interactions and excludes the inherent features of the elements. It considers three parts: Interactions’ Importance, Multi -Attribute Evaluation of Elements and the Coordination level.

Interactions' Importance: They provide an evaluation of the MIG matrix display in order to categorize the interactions and facilitate their interpretation. This evaluation uses four categories (depicted by colors): > 75% (Darkest dots), > 50% (dark grey dots), >25% (light grey dots), <25% (white dots) and 0% (w/o dots). This scale depicts the logic of the Likert scale -1 (nil) to 5 (max)- used in the closed questions of the field survey. In the case of direct data (Q1, Q2, Q3, Q4 & Q7), it depicts direct outputs from the survey. The logic of the calculated links (indirect data) is similar because they are constrained by the values of the Likert scale.

Multi-Attribute Evaluation of Elements: It assesses the elements' importance based on the interaction density of Q1, Q5 & Q9, feedback (FF) and feedforward (FB) quadrants. The density (ratio of observed over potential interactions) represents the frequency of interaction. The FB and the FF depict the sum of all the inputs and outputs of each element i.e. for Q1, FF=f(Q4, Q7) & FB =f(Q2,Q3), then for Q5, FF =f(Q4,Q8), FB =f(Q2,Q6) and finally for Q9 FF =f(Q7, Q8) and FB = f(Q6, Q3). Finally the elements' importance is calculated as: Importance = Frequency*FF*FB.

Coordination: It is evaluated using the interactions' density. This index is calculated for Q1 (team), Q5 (meetings), Q9 (process) and for the overall matrix.

Tracking

The tracking of MIG matrices depicts the evolution of their descriptive indexes and of their structural configuration displays over time. This assessment depicts the existence of isolated elements (with a lack of interactions, so vulnerable to underperformance), of clusters (highly interconnected elements, so vulnerable to failure), and of critical elements (connected to every one).

Table 2: Project Features

Characteristics	Description
Project Type/Scope	Housing, 121 Houses, From 65 to 94 square meters
Team (12 Persons)	01 Site Manager, 02 Project Engineers, 01 Warehouseman, 01 Superintendent, 01 Safety Engineer, 01 Administrative, 03 Foremen, 02 Subcontractors
Key Items (Cost %)	Masonry (26%) Sanitary Installations (18%), Painting (11%), Concrete (11%), Interior wood work (10%)
Bottleneck	A procurement activity centralized in the headquarters

RESEARCH METHODOLOGY

The goal of this study was to test the MIG prototype. The work was carried out by using the case study logic; it involved first developing the tool concepts, then testing them and finally considering improvements. The test process itself encompassed five stages: Data Collection (by field survey), Matrix Building, Index Calculation, Tracking & Reports Queries, and finally Outcomes Analysis. The test relied on a project in construction stage (housing) located in Santiago de Chile (Table 2) that used the LPS. The information was collected weekly during five weeks and generated 1,617 records, reflecting the outcome of questions asked of 12 team members about their team interaction, their meeting attendance and their use of LPS. Finally the information was loaded into a MS Excel database.

RESULTS

The key MIG results are the Operational and the Strategic Matrices. Only the last one is exhibited here (Figure 3). Also a summary of the main outcomes from these matrices (Table 3) and an example of index tracking (Figure 4) are depicted here.

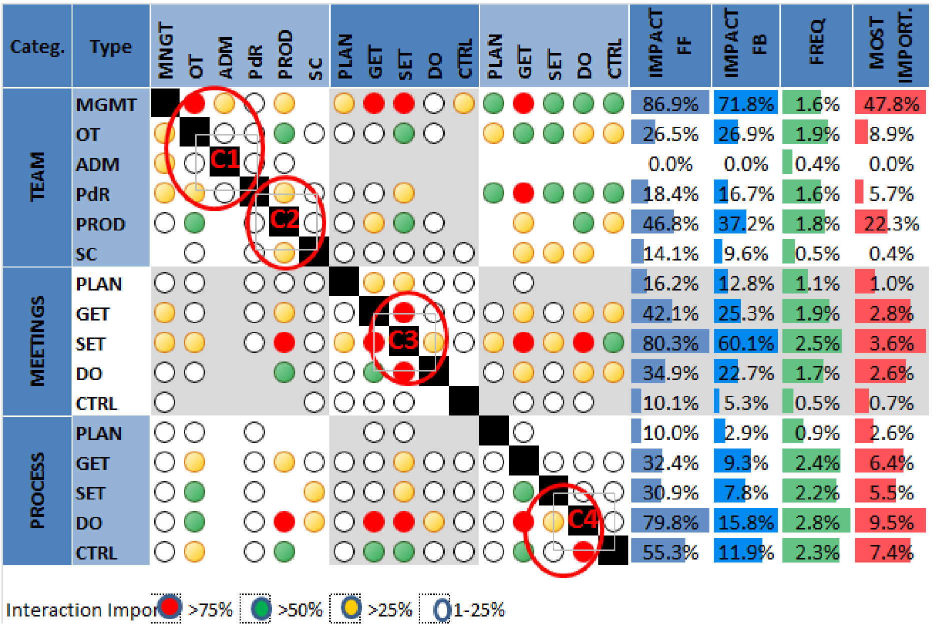

Figure 3: MIG Strategic Query (Average values) (level 1.1)

Table 3: Main Outcomes from Strategic and Operational Matrices

Key Items	Team (T)	Meetings (M)	Process (P)
Interactions*	MGMT⇦OT	Get⬄Set, Set⇨Do	Get⇨Do, Do⇨Ctrl
Important functions	MGMT, PROD	SET, GET	DO, CTRL
Clusters Location	Office, Prod.	Around Set	Toward process end
Most Important operational elements	- Site Manager - Superintendent	- Weekly Meetings - Daily Orders	- Weekly Schedule - Improvement Process

*(⇨) Feedforward link of A on B, (⇦) Feedback link of B on A and (⬄) A&B interaction.

ANALYSIS

The MIG is a tool for the analysis and management of the production planning and control function. The goal of this work has been to test a prototype tool, which exhibits capabilities for identifying key elements and for evaluating the structure of the PCF supply, considering the team, meetings and managerial processes involved.

Team: The most important sub-teams are management (MGMT) & production (PROD). Their relevance is caused by the presence of the project's critical individual agents, i.e. project manager and superintendent. These individual agents generate the most frequent and important interactions, plausibly as part of their duties.

Additionally these two sub-teams lead the meeting attendance, LPS use (PROD only) and also they are the most important receptors of information from meetings and LPS. Their rich amount of dependences produces the clusters of interactions C1 & C2.

Meetings: The most important meeting type is SET, although GET & DO also rank high. The SET relevance is caused mainly by three meetings which concentrate the most important interactions: (1) weekly coordination meeting, (2) daily staff coordination meeting & (3) daily stand- up instructions meeting. They define a critical hub where the most important inputs and outputs from Team and LPS converge, generating the C3 Cluster which may be the potential focus of coordination

Process: The most important managerial processes are DO & CTRL, albeit GET & SET also rank high. Their relevance is driven by the weekly scheduling and by the sub-process that studies the reasons of non-compliance. They receive and generate the most important inputs and outputs from team and meetings. In Q9, the cluster C4 suggests that feedforward dependences are stronger than the feedback ones and are located toward the end of the LPS processes; this may suggest a reactive coordination.

Tracking: Over time The MIG is depicted by time series indexes and by their corresponding structural displays. Fig. 4 depicts the frequency index evolution for team and meeting (average value) where an inverse relationship seems plausible; lower levels of team interaction may be compensated by more meeting interaction.

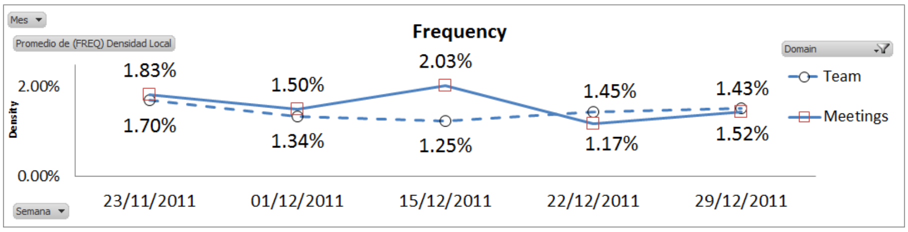

Figure 4: Frequency Index Tracking: Team and Meetings

DISCUSSION

The tool provides a framework for describing, analyzing, tracking and potentially for regulating coordination over the PCF supply. The tool depicting management emphasis may detect potential weak points and hence detect improvement options. The following comments refer only to the strategic matrix due to space limitations.

Team: The social interaction could be improved. A fragmented interaction pattern deteriorates response under stressing conditions (Krackhardt and Stern, 1988). In Q1 fostering the merge of the C1 & C2 clusters seems convenient to increase interaction, which between Management (MGNT) & Subcontractors (SC) is nil and between Administrative (ADM) Technical Office (OT), Production (PROD) & SC is poor/nil.

Team, Feedforward (FF) & Feedback (FB) Links: The links of Team with meetings and process could be improved. First, MGMT values the FB obtained from meetings and processes (i.e. dark dots over Q2 & Q3) but it exhibits a low proactive action on them (Clear FF dots on Q4 & Q7). Then ADM seems isolated; it does not interact with meetings & process i.e. nil FF & FB (in fact, the person in this role was frequently absent from the job site because he was working with another project too). Next, Safety (PdR), receives FB but its proactive involvement with meetings (e.g. FF in DO is nil) and processes is low. PROD is mainly proactively involved with SET & DO meetings and DO & CTRL processes, while the links between PROD and PLAN in both cases are poor (in fact the project did not use phase scheduling). Finally, the SC links are even weaker than those of PROD, showing various nil and low links.

Meetings: The network of meetings could be improved. The meetings catalyse the effect of team on processes (Priven and Sacks, 2013) In Q5, the improvement of interactions by pulling the focus of cluster C3 toward PLAN and GET could generate positive outcomes due to an increased level of anticipatory action. DO & CTRL do not interact, indicating potential poor learning activities.

Meetings, Feedforward (FF) & Feedback (FB): The links of Meeting with LPS could be improved. The meetings seem to regulate the LPS processes mainly by acting proactively on DO (dark dots on Q8) and by receiving FB from GET, & DO (dark dots on Q6); however the interaction between meeting and PLAN is low.

Process: In Q9, the LPS processes' interactions require improvement. First, the FB links are mainly poor and in the case of PLAN they are nil ; this is a condition which may suggest possible poor learning (Sterman, 2000). Then the cluster C4 could be pulled toward GET & SET, fostering action in the upstream LPS processes.

Practical Contribution: In summary, the contributions were:

- An improved PCF supply description. This implies the use of elements (team, meetings & interactions) up-stream the managerial processes that potentially impact the variability propagation over the PCF (Zegarra and Alarcón, 2013).
- A framework for tracking and potentially for tuning the PCF supply. It tries to provide a kind of "value stream map" of the PCF supply and its managerial processes, providing a strategic level view of this system (Figure 3).

Relationships to other PCF tools: The MIG aims to complement other tools for PCF supply. The tool aims to provide an additional view to help PCF supply improvement. The MIG benefits also could be provided, in some way, using the Social Network Analysis (SNA) (Priven and Sacks, 2013) albeit, from a weaker perspective because SNA has a more limited view of causal structure than the DSMs.

Limitations: *This paper represents on-going research*. There are issues which still need attention such as the simplification of MIG inputs, the dependences calculation, & the inclusion of element features in the multi attribute evaluation among others.

Theory Contribution: The objective of MIG is to depict the coordination efforts over the complex structure of the PCF supply. The description uses two special DSMs which include interdependent elements from social & process domains, both at strategic and operational levels (Lindemann, 2015). The causation of this arrangement may be complex because it involves the interaction of elements from different domains and hierarchies. The operational level (by bottom-up causality) generates the emergence of the strategic level; that, in turn, by top down causality, drives the operational level regulation (Ellis, 2008). Finally coordination has been defined as *"managing dependences between activities"* (Malone and Crowston, 1994); in this sense, MIG aims to depict and manage these dependences over the PCF supply.

CONCLUSIONS

The MIG is a tool for analysis and management of PCF itself. It involves two special type of DSM, each depicting interacting teams, meetings and managerial processes. It may depict the coordination effort features over the complex, hierarchical and multi-dimensional structure of the PCF supply mechanism. The MIG's most important implications are its capabilities for describing, analyzing and potentially for regulating the PCF supply structure. The final stage of this work is going to test a hypothesis of performance improvement of the PCF supply, based on the diagnostic and handling of the clusters of interactions.

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INTEGRATION OF LAST PLANNER SYSTEM AND LOCATION-BASED MANAGEMENT SYSTEM

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ABSTRACT

The Last Planner System (LPS) and Location-Based Management System (LBMS) are both lean planning and controlling tools. A combination of these systems would bring much greater benefits than stand-alone implementations. However, previous research attempting to combine these methods has not been on sufficient level of detail for actual implementation.

The goal of this research is to develop a combined workflow for master planning, phase planning, look-ahead planning and weekly planning. The workflow is demonstrated through the use of a simple example from a case study project. Master scheduling clearly belongs to the domain of LBMS; time and weekly planning is clearly within the domain of LPS. Phase scheduling can include components from both systems but integration is straightforward. The biggest opportunities for improvement exist in progress tracking, forecasting, control action and look-ahead planning phase where LBMS and LPS both have important independent contributions and their combination is not trivial. The paper attempts to better define the inputs and outputs of each system in each phase to come up with a unified solution. A case study example will help practitioners implement the combined method.

KEYWORDS

Last planner system, Location-based management, production planning, production control

INTRODUCTION

The Last Planner System® (LPS) and Location-Based Management System (LBMS) are complementary lean production planning and controlling tools which aim to decrease waste, increase transparency, improve predictability and improve flow. LPS does so by focusing on the social process of collaborative planning and by improving the reliability of commitments (Ballard, 2000). LBMS is primarily a technical system which optimizes work continuity based on quantity and productivity information and forecasts future performance (Kenley and Seppänen, 2010). The systems complement

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each other well because they have no technical overlap. For example, the LPS process of phase scheduling could be implemented using various scheduling formats, including LBMS. The proposed integration uses the social process of LPS with the technical tools of LBMS. The combination of these systems has been proposed previously (Seppänen, Ballard and Pesonen, 2010) but the research was exploratory in nature and the description of the process did not contain sufficient detail for empirical research or industry application. The goal of this paper is to update and add more detail to the proposed combination of the two systems.

The proposed process is divided into two parts: production planning and production controlling. Production planning is understood to include master scheduling and phase scheduling. Master schedules in LPS are limited to milestones and long lead items (Ballard, et al., 2002, pp. 227-229). More detail is added collaboratively in phase schedules where planning starts from the milestone and works backwards so that each task releases work to the next task (Ballard and Howell, 2003). In terms of control, project and production control can be distinguished. The job of project control is to determine if the project is moving toward its objectives. The job of production control is to proactively move the project to achieve those objectives. From this perspective LPS works mostly on production control while LBMS has tools for both project control and production control.

A key requirement for lean production planning and control methods is to make problems visible as early as possible and subject them to root cause analysis, problem solving and continuous improvement according to the Plan-Do-Check-Act cycle (Deming, 1986). LPS and LBMS both aim to uncover these problems. The discussion in this paper focuses on how more problems can be identified earlier by combining the two methods.

CASE STUDY

A case study will be used throughout the paper to illustrate the concepts in a real project. Webcor Builders, a large general contractor operating mainly in the West Coast region of the United States, is the prime contractor. The client is a private company with headquarters in South San Francisco. The client has a new construction expansion plan of their facilities. The plan consists of two phases, an office building of 23,690 m2 (255,000 sqft) in the first phase and an employee center with fitness club in the second phase. The contract type is Highly Collaborative Project Delivery, which is similar to IPD but does not include the three party agreement. However, working in a big room, performance incentives and collaborative planning were core requirements used to select the project team. The project was discussed related to social aspects of LBMS implementation in IGLC 2014 (Freeman and Seppänen, 2014). After that study, LBMS and LPS were implemented together with a contractual CPM schedule.

PRODUCTION PLANNING

MASTER SCHEDULE

Production planning in Last Planner System is divided into Master Schedule and Phase Schedules. Master schedules of LPS are typically limited to phase milestones and long lead time items (Ballard, et al., 2002, pp. 227-229). However, Last Planner principles do not prohibit producing a detailed master schedule (Ballard, Hammond and Nickerson, 2009). Seppänen, Ballard and Pesonen (2010) proposed that LBMS could add more definition to the master scheduling phase by defining the overall Location Breakdown Structure (e.g. project divided first to separate buildings, then to floors, then to zones) and to evaluate the required production rates. In LBMS, Location Breakdown Structure specifies the physical locations where work will be done. Different phases can follow different LBS's but all work within a phase is planned and controlled using the same locations. Locations can be hierarchical and logical relationships can be automatically created based on levels of hierarchy (e.g. all work of predecessor needs to be finished in a building before the successor can start in the same building) (Kenley and Seppänen, 2010). Master schedules were recommended to have 20-30 tasks, using available quantities and resource information where possible.

In master scheduling phase, there is generally limited availability of information about design. However, in almost all cases the main trades and main tasks to be carried out are known. It is also possible to know or reasonably assume many key quantities based on schematic design and building function. Location-Breakdown Structure on rough level (Buildings and Floors) can be designed, as well as overall production flow. How can we get into good phase milestones by using all this available information but not going into too much detail?

We propose that the focus should be on tasks with mandatory technical hand-offs to other trades and on tasks which require a lot of space for laydown areas and work. Tightly interrelated tasks such as form-rebar-pour sequences and overhead MEP can be lumped into one task. Additional buffers should be reserved for tasks which contain work of multiple subcontractors.

The overall strategy of the master schedule will likely have to be followed because it will be used to pull design and schedule long lead time deliveries and to discuss with subcontractors during buy-out phase. However, any dates and task names will likely change during the phase scheduling process. The exact dates of the master schedule should never be used to push production to start on a given date. Rather, it gives preliminary information for any phases which have not yet gone through collaborative phase scheduling exercise.

In the case study project, Webcor's project team developed an LBS which was broken down by buildings, level and for interiors to five zones on each floor. The team developed a master schedule based on an internal pull scheduling meeting before subcontractor buy out using experience gained from past similar office buildings. The plan was based on continuous workflow with one crew flowing from the first floor to the seventh floor for each main task. The plan was optimized for flow using LBMS and visualized with flowline diagrams (not shown here because of space constraints). The extended project team got the schedule in Gantt Chart format.

PHASE SCHEDULE

Phase scheduling using pull planning principles has been discussed extensively (see for example Tsao and Hammons, 2014 for a great practical case study). When combining LBMS and LPS, Seppänen, Ballard and Pesonen (2010) proposed having two workshops, one for location-breakdown structure and task and logic definition and second for schedule optimization with a homework assignment in between where all the parties collect quantity and productivity data for each task. We recommend the same process but try to go into more practical detail in this paper.

First, a common Location Breakdown Structure should be defined. The goal should be to achieve similar quantities of work in each location with each trade able to finish work in one location completely before moving to the next location. One of the key decisions at this stage is location size. Large locations mean implicit buffers because if locations are large, it typically would be possible to have several subcontractors work in the same area. Very small locations can be hard to define so that they work for all or most of the subcontractors and it may not be possible to stage all the materials within the location.

In practice, defining the Location Breakdown Structure is easiest with printed floor plans. The facilitator of the meeting needs to make sure that each participant understands that a location must be able to be fully completed before moving to the next location. Subcontractors often request their own custom locations to locally optimize productivity but can be persuaded to adopt a common location breakdown structure when they understand that they will be able to own the location.

Pull scheduling can then be done using sticky notes, focusing first on standard work for each location type. For example, an office building could have different pull plans for cafeteria, office rooms, corridors and elevator lobbies. Different pull plans are not required for minor location-based exceptions. They can be handled with additional location-based sticky notes. If a location has a lot of exceptions, a separate pull plan should be considered. Durations should not be discussed at this time because the goal of the exercise is to get tasks and logic. Durations will be an outcome of the schedule optimization step (Seppänen, Ballard and Pesonen, 2010).

The first workshop results in a Location Breakdown Structure, a list of tasks and their logical relationships. The next step is to collect the remaining data required to create a location-based plan – quantities, labor consumption rates (manhours / unit) and resources. Quantities are required for each task and each location where the task exists. The same labor consumption is assumed to apply to each location, unless productivity is expected to be different due to changing difficulty. Resources and crews are based on optimum minimum crew size. For example, electricians can work productively alone (optimum crew = 1) but windows and doors require teams of two (optimum crew = 2). Additionally subcontractors can provide information of how many crews of optimum size they are planning to mobilize for each task. This information can be collected off-line by giving all participants an Excel spreadsheet template with task names in rows and labor consumption and quantities in locations in columns.

Before the schedule optimization workshop, the first location-based plan is created. This is strictly based on information collected in the workshop and based on quantity and labor consumption information provided by the subcontractors. The first schedule has continuous flow for all trades, logic based on pull scheduling workshop and resources based on subcontractor suggestions. In almost all cases, the first schedule significantly exceeds the master schedule milestone.

Schedule optimization is done collaboratively in the schedule optimization workshop. The best place to start is with tasks with largest empty spaces before them in the flowline diagram. For each task causing an alignment problem ways to improve productivity are discussed first. If it is not possible to improve productivity, more resources are requested from the subcontractor. Additional resources are added until the slope of the task matches the predecessor. If it is impractical to add that many crews to work in one location, splitting the task into multiple workflows can be considered. If the subcontractor does not feel comfortable committing to required crew size, the first round of optimization goes up to the team size that is acceptable to the subcontractor. If the task is proceeding too fast, options include accepting discontinuous work, decreasing resources or adding more work to the scope. Issues are resolved in this manner one at a time until improvements can no longer be made within everyone's comfort zone.

If the target milestone cannot be reached during the first round, a second round is added where the team brainstorms about possible solutions. Because all the participants realize that targets could not be met within their comfort zones everyone should be more willing to make concessions after having gone through the process once. Often innovations, such as adding more prefabrication or removing any responsibility for logistics from bottleneck contractors, are proposed and can decrease resource requirements to balance the phase. The end result is a balanced flowline schedule which finishes before the master schedule milestone. Buffers can then be added within the phase to protect the flow of bottleneck operations. Once approved by all parties, the phase schedule replaces the corresponding part of the master schedule.

In the case study project, all trades involved in the phase were contacted prior to the pull planning meeting. The participants were asked to list their specific deliverables for this milestone and define the necessary steps they would need to achieve the deliverable. At the same time they were asked to develop their preferred LBS, sequence of locations, crew size and production rate for that crew size. The project team prepared for the meeting by having done a first draft schedule and production plan with a detailed LBS and production rates. In the pull planning meeting the LBS was first discussed and agreed on. After agreeing to the LBS the trades pulled from the milestone through one standard location. The results were analysed using LBMS. Optimization discussions were done as follow-up meetings with the impacted trades.

Figure 1 shows the interior rough-in phase schedule from the case study project for Building B. The schedule changed significantly from the master schedule based on the planning meetings. The phase was detailed out by adding several more tasks for each trade based on pull scheduling process. In the master schedule, each subcontractor had one crew flowing through floors in sequence. In the phase schedule, two crews working different floors were implemented for most trades (floors 2-4, floors 5-1). The special areas of the first floor were placed last in sequence and many trades have additional crews in that location. Most of the tasks are continuous but some have been planned to be. A few faster tasks flow continuously through floors 2-7 and do not have a separate crew for level 5-7.

PRODUCTION CONTROL

LOOK-AHEAD PLANNING

In the Last Planner System, lookahead planning (preparation) consists of constraints identification and removal, replanning when necessary, task breakdown to the level of operations, and collaborative design of new operations (Hamzeh, Ballard and Tommelein, 2012). Operations consist of steps which are appropriate for assignment to individuals or sub-crews within a crew. Designing at operation level reveals different constraints, and having a tested design (virtual prototyping, physical prototyping, or thought experiment) increases the probability of reliable release of work downstream (Hamzeh, Ballard and Tommelein, 2012).

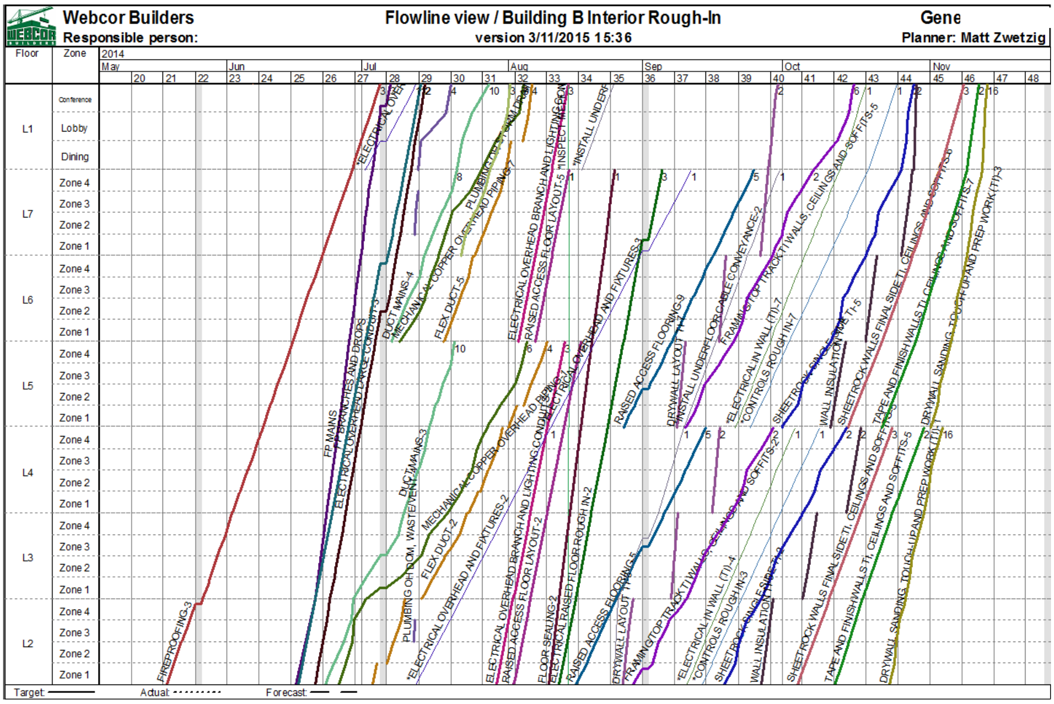

Figure 1: End result of phase scheduling optimization meeting for interior rough-in milestone in case study project

LBMS is concerned with cascading delays caused by interference between trades (Seppänen, 2009). The main control tools include systematic collection of progress data, forecasting future production based on actual production and alarming of upcoming interference. Constraints or operations level are typically not incorporated to the LBMS schedule because they could lead to cluttering and decrease of visual effectiveness of flowline diagrams (Seppänen, Ballard and Pesonen, 2010). However, constraints are critical to include in the analysis, or unplanned work stoppages or slowdowns may occur which have nothing to do with interference from other trades.

LPS and LBMS are very complementary with regard to look-ahead planning because they raise different problems for discussion. The LPS process exposes constraints which must be removed for production to continue according to the plan without interruptions. LBMS highlights problems related to capacity and production rates. All of these problems can be analyzed through root cause analysis and solved collaboratively.

Seppänen, Ballard and Pesonen (2010) proposed that the combined look-ahead process works by updating LBMS forecasts for discussion in a superintendent meeting devoted to lookahead planning. The complete weekly look-ahead process would thus include the following steps (not necessarily in the sequence below and allowing for some iteration):

- Identify tasks and locations in the look-ahead window
- Break down tasks and locations to operations
- Identify, assign and remove constraints
- Review actual production to identify ongoing production problems
- Review forecasts and alarms to identify future production problems
- Root cause analysis for problems
- Re-Plan to address current and upcoming problems
- Release constraint-free operations, tasks and locations to workable backlog
- Preparing for upcoming operations

These steps are elaborated below.

Identify Tasks and Locations in the Look-ahead Window

Tasks and locations in the look-ahead window are identified based on the LBMS phase schedule. This can be done graphically on production wall by drawing a line through the flowline diagram and listing all tasks and locations where flowlines are to the left, or intersecting with the look-ahead period line.

Break down tasks and locations to operations

Tasks in locations are broken down to operations level in a pull scheduling session with the team responsible for the task. The team needs to come up with the answer of what steps are required for the task to be finished in a location. This should be reviewed for both the task in general (what is common in all locations?) and by location (specific operations related to that location). For example, for a task called stud framing in phase schedule, operations could include layout, moving materials to the right location, installing bottom track, plumbing the top track, installing top track, installing bottom track, cutting studs to correct length, installing studs and installing backing. Different circumstances and their impact on operations should also be considered. For example, the attachment of top track depends on whether it is attached to concrete, metal deck or joists and any special circumstances may include different operations.

Identify, assign and remove constraints

Any missing constraints related to operations, tasks or locations are identified in meetings with the team responsible for doing the work and in weekly superintendent look-ahead meetings. A constraint can apply to the whole operation (for example, material not delivered) or a certain location (for example, open Request for Information on the fifth floor related to Drywall Framing). Identified constraints are assigned to team members who commit to their removal by a certain date. Currently active constraints are reviewed weekly and their status is updated. If a constraint cannot be removed before the LBMS forecast date, the constraint will be elevated into a problem.

Review actual production and forecasts to identify ongoing production problems

Progress data is collected and analysed with LBMS to identify start-up delays, production rate deviations and work interruptions. Forecast is calculated based on actual labor consumption rate and current resources on site. Any alarms caused by current or future interference between trades are elevated to problems.

Root cause analysis and resolution for problems

Any problems identified through constraint identification, constraint removal or actual production are analysed for root causes (Ballard, 2000). LBMS will provide numerical support - such as actual production rate and actual labor consumption - for any discussions related to production deviations. Actions are agreed with the team to target these root causes. If the agreed on actions impact the crew size or anticipated future productivity of an operation, the forecasts are recalculated with these values to see if the actions are enough to prevent the problem.

Re-Plan to address current and upcoming problems

Re-planning can be initiated to address current or upcoming issues which cannot be dealt with by productivity improvements or crew adjustments, or if a better way to finish the phase has been proposed. Re-Planning can change any aspect of the phase schedule and can be organized in the same way.

Release constraint-free tasks and locations to workable backlog

When all constraints related to all operation of a task in a location have been removed, the location is released to workable backlog. The control chart is a good visual way to keep track of workable backlog. In control chart, the location-breakdown structure is shown on vertical axis and phase schedule tasks on horizontal axis. Tasks in a location are color-coded based on constraints and status. Any tasks with constraints in a location can be shown in grey color (Kenley and Seppänen 2010, p. 329). Although operations belonging to a task can also be constraint-free, they should generally not be started until all operations can be performed before handing off the location to the next trade. Starting individual operations would result in work-in-progress of no value to the downstream operation.

Designing upcoming operations

Before the start of an operation in the first location, the operation should be explicitly designed by those who are to execute the operation. The design of operations can be done using virtual prototyping, physical prototyping or first run studies. Standardization is appropriate for new, critical, and repetitive operations. Critical operations, such as heavy lifts, are those whose failure cannot be tolerated, and so warrant extensive planning and preparation. Planning and preparing for new operations, such as assembly and installation of light fixtures, helps avoid rework and work flow interruptions. Repetitive operations may benefit from virtual or physical prototyping (mock ups), but can also be refined over multiple iterations. That starts with a design session involving the craft workers who will do the first run (the first instance of the repetitive operation), documentation (videotaping, process maps, etc.) of the work as actually performed, and review with the craft workers to develop further improvements (Parker and Oglesby, 1972; Oglesby, Parker and Howell, 1989; Ballard, et al., 2002; Ballard and Howell, 2003).[4]

[4] The expression “first run study” appears to have originated in the writings on Last Planner by Gregory Howell and Glenn Ballard, but the basic methodology was brought into the construction

Examples from the case study project

In one of the weekly meetings the electrical contractor complained of trade damage to his electrical under-floor installations, which required rework that caused delays. A root cause analysis of the problem found that the time between the electrical installation and the following trade putting in the raised access flooring was too long, and construction traffic and material transportation through the area damaged the completed electrical work. LBMS analysis showed that the electrician was installing faster than planned. The team decided to adjust the production rate of the electrician back to the initial planned rate to be almost at the same speed as the following accessed floor installation. In this case LBMS provided the tools for planning corrective actions to problems found with LPS tools.

Another example related to steel erection. The actual installation rate was significantly faster than the rate planned in phase scheduling. LBMS analysis showed that the steel erector would outpace welding and plumbing crews and cause a break in the flow of work. The decision was made to stop the steel erection to have the following operations catch up. The crew that continued work had a slower production rate than planned and failed the LPS commitments. The root cause analysis revealed that the first team was the “A-team” and the second crew was the “B-team” and they both deviated from the planned installation rate. In this case, LBMS highlighted the problem of going too fast and LPS highlighted the problem of going too slowly. With stand-alone implementation one of the problems would have been found much later if the project had been implemented LBMS or LPS alone.

WEEKLY PLANNING

The main strength of LPS is efficient execution based on commitments, collaboration and continuous improvement as a result of analysing plan failures. Root cause analysis is initiated for any assignments which were not completed as planned (Ballard, 2000). The proposed integration with LBMS on weekly planning level is to compare commitments to LBMS forecasts to highlight problems earlier. If commitments do not match or exceed the LBMS forecast, it is possible to know a week earlier that there will be issues. In the combined system, weekly planning highlights problems in the commitment phase through LBMS comparison and after execution through plan failures. Both the upcoming and actual problems should be subjected to root cause analysis and learning process.

CONCLUSIONS

In this paper, a process combining LPS and LBMS was described based on current best practices and using examples from a case study. With regards to production planning, the process described earlier by Seppänen et al. (2010) was elaborated in more detail. However, new ideas were presented particularly in relation to production controlling. A critical part of production control is highlighting as many problems as possible, as early as possible. It was found that the combined system looks at the production system from multiple different angles and is able to identify more

industry by Parker and Oglesby (1972) and further elaborated by Oglesby, Parker and Howell (1989).

problems earlier than stand-alone implementation of either system. LPS constraint screening will reveal some problems, LBMS forecasts and actual data will reveal others. Finally, weekly planning will reveal problems if commitments do not match the required production rate and if the team fails to meet those commitments. These problems can then be subjected to root cause analysis and continuous improvement through Deming's PDCA-cycle. A few examples of problems were illustrated using a case study from Webcor. Previous research has reported the amount of problems found by LBMS (for example Seppänen, 2009; Seppänen, Evinger and Mouflard, 2014) and LPS (for example Ballard, 2000). Anecdotal evidence from the case study shows that the amount of problems identified increases and information from the combined system helps in solving the problems. This hypothesis needs to be tested in future empirical research.

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THE STANDARDIZED WORK TOOL APPLIED TO THE WATERPROOFING PROCESS WITH ACRYLIC MEMBRANE

Nádia B. L. S. Fernandes[1], Angela B. Saggin[2], Caroline P. Valente[3], Felipe L. Brito[4], and Carlos Alexandre M. A. Mourão[5]

ABSTRACT

The Standardized Work is a lean tool that looks for process stability and productivity gain, by defining three main elements: precise work sequence, takt-time and standard inventory. This paper's main goal is to present the implementation of the Standardized Work tool for the waterproofing process with acrylic membrane at a construction site from a Brazilian building company to improve productivity, work conditions and precision in service's execution.

The methodology for developing this study case includes monitoring the waterproofing service, charting the collected information, analyzing data and graphics obtained, proposing a new sequence of activities and discussing it with the production and management teams. The production team supervisor has daily observed the new work routine established and the analysis has shown a 33.33% of productivity increase related to the initial stage. Furthermore, one member of the production team received a promotion, the team has better work conditions and instruments that are more adequate for the service execution, improving safety and reducing ergonomic risks to workers. Finally, the management team has improved its control and accompaniment, facilitating the knowledge management.

Therefore, the company identified the implementation of Standardized Work as an original, functional, feasible and easily replicable tool to other construction services.

KEYWORDS

Lean construction, standardization, production, waterproofing, productivity.

INTRODUCTION

According to Ohno (1997), despite the mass production system has been successfully applied in Japanese industries during the 60s and 70s, the team at Toyota Motor

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Company believed that production model would not be sustainable in long-term, in view of its susceptibility to error and, therefore, excess waste generated. Thus, the company sought to develop a production system that would allow greater flexibility of models, with low costs and complete elimination of waste. The Toyota Production System (TPS) was then formulated.

From the changes of paradigms introduced by the Toyota Production System (TPS), Lean Production emerged, whose main objective is to add value to the customer through the complete elimination of waste. Thus, this production system has the following characteristics: inventory reduction, strict quality control, minimization of defects, adding value to the final product, employee's autonomy, anticipating problems and cooperation with suppliers (e.g. Womack, Jones and Roos, 1990).

Based on this, Womack and Jones (2003) expanded the concept of lean production to other areas of an organization through Lean Thinking, guided by five principles: value, value stream, continuous flow, pull production and pursuit of perfection.

In the 1940s, during World War II, the Training Within Industry Service (TWI) was started and developed to assist war production industries. Based on the philosophy ‘every supervisor has five needs’ (knowledge of the work and responsibility, skill in instructing, in improving methods and leading), it was developed the J-Programs, a four-step method of training: job instruction, job methods, job relations and program development (e.g. Huntzinger, 2005).

The standard work resulted from the Job Methods program, that establishes the ability to break down a process into its critical steps, and from the Job Instruction program, which allows knowledge transferring (e.g. Feng and Ballard, 2008).

According to Mariz (2012), the Standardized Work corresponds to the operational tool of the principle of continuous flow. The intent of the standardized work is to define the best methods and to reduce variation in the process steps as much as possible and not making all tasks repetitive (e.g. Feng and Ballard, 2008). Thus, this tool aims to establish the exact procedure of executing a given service through three elements:

- Standard sequence of activities: It corresponds to the sequence of activities in which a worker processes production units (e.g. Ohno, 1997);
- Takt-time: It corresponds to the production time in relation to customer demands (e.g. Dennis, 2008);
- Standard inventory: It corresponds to the minimum amount of items required for the production flow to remain continuous (e.g. Dennis, 2008).

According to Feng and Ballard (2008), standard work is a foundation of lean implementation and allows analysing the critical steps of a process. The standard work requires identifying the processes’ tasks variety (low or high) and analyzability (low or high). It is also essential to determine the critical, important and low importance tasks within the process.

CASE STUDY DESCRIPTION

OBJECTIVES

This research paper has the main objective to apply the Standardized Work tool for waterproofing service with acrylic membrane in a residential project of a construction company from Fortaleza, Brazil. Thus, there is the expectation of increased staff productivity through the proposition of a better sequence of activities and minimizing parts of the work that do not add value.

The specific objectives relate to the provision of better working conditions for employees and greater precision in the execution of the service. Despite having been chosen to present its implementation in waterproofing service with acrylic membrane, the Standardized Work is applicable for many services performed at construction sites.

THE CONSTRUCTION COMPANY

Founded in 1977 at Fortaleza, Brazil, the construction company of this case study focuses specifically to Classes A and B. It has more than 700.000m² of constructed area, distributed in various residential projects.

Since 2004 the company has been using many lean tools and practices: *kanbans, andon, poka-yokes,* supermarket concepts in the warehouses, transparency, production in small batches, new solutions formatted in the A3 tool, the standardized work tool and many others.

In 2010 the successful implementation of lean construction allowed the union of Lean System with the Quality Management System, resulting in the ISO 9001 Lean System of Quality certification, the company's current management model.

THE PROJECT

The research was conducted in a residential building (Figure 1) located in noble neighbourhood of Fortaleza, Ceará. The project consists of a single tower with 23 floors and four apartments per floor. It also has four options of floor plan and large recreation area, with completion due to January 2016. The project's gross area is 18,311m².

Figure 1: Project's façade and apartments plan (courtesy of the company)

Until early 2014, the waterproofing of wet areas occurred through the application of asphalt mantle held by a third party. In 2014, the company decided to use a new material, the acrylic membrane, which is easier and safer to apply as well as it is executed by the company's own employees.

A two-person team, consisting of an auxiliary and a professional, conducts the waterproofing service. The team had a productivity of 12 apartments per month, which corresponds to 1.75 days per apartment (or 18.06 min/m²). The takt-time was determined by the goal established by the management team, based on the upcoming services productivity such as flooring. The goal was to complete 11 apartments per month, which corresponds to a takt-time of 2 days per apartment (or 20.65 min/m²).

In addition, the company already has a work instruction for the service and the employees demonstrate familiarity with the sequence of activities, but they do not have a standard execution. So, the work team had difficulty in controlling production as well as identifying opportunities for improvement.

DEVELOPED ACTIVITIES

This case study occurred into five stages:

Characterization of the initial stage: the first methodological stage was to observe and monitor the execution of waterproofing service with acrylic membrane, in order to characterize the initial stage. Thus, the work team was accompanied for two shifts, so that all activities had their times monitored, whether inherent to the process or not. Figure 2 presents the application of the first painting with the product, as well as a sample of a sealed area.

Figure 2 – Waterproofing process with acrylic membrane (courtesy of the company)

- Tabulation of collected data: after the initial collects, qualitative and quantitative information were tabulated and compiled in spreadsheets in order to generate graphs and relevant data to the study. Figure 3 shows an example of tabulation of the observations.

Simplified Process Study Form (PSF)						
Period	Time	Interval	Ativities	Comments	Room	Cycle or out of cycle
Morning	07:57:00	00:01:56	Preparation of materials	Polish machine, PPEs, extension cord, etc.	Kitchen, service area, bathroom and balcony of 1103.	Out of cycle
Morning	07:58:56	00:05:08	Thick cleaning	Removal of ceramics, bags, pallets, etc	Kitchen, service area, bathroom and balcony of 1103.	Out of cycle
Morning	08:04:04	00:03:21	Preparation of materials	Pick up a light bulb, turn on the extension cord, pick up a brush, pick up a broom.	Hall of the 11th pavement, between appartments 1102 e 1103.	Out of cycle
Morning	08:07:25	00:00:45	Thick cleaning	Sweeping	Kitchen, service area, bathroom and balcony of 1103.	Out of cycle
Morning	08:08:10	00:01:44	Stop	Identified a leak and called the responsible team.	Kitchen, service area, bathroom and balcony of 1103.	Out of cycle

Figure 3– Tabulation of collected data

- Identification of critical activities: the third stage was the proper analysis of data and graphics. Thus, it was intended to identify which were the most critical activities of the service, how the parts of the service that did not add value could be minimized, how the activities of the cycle were distributed and what could be the most appropriate intervals of time for completion of the service.
- Standardizing the waterproofing work team routine: based on the analysis of the stage three, it was suggested a new standard of work. Thus, the fourth methodological stage corresponded to the adjustments made to the sequence of activities in order to minimize the cycle time, promote greater control by employees and supervisors and increase team productivity.
- Presenting the standardized routine to management and work teams: meetings were held with senior management and the work team. The first one aimed to explain the study, present the planned improvements and seek for commitment of managers to the research in order to maintain the daily monitoring of the activities and the maintenance of new work conditions for the proper execution of the service. The second one aimed to present the proposition of the cycle of activities, as well as to confirm with the team about its feasibility of execution.

CASE STUDY IMPLEMENTATION

Because the company already had the work instruction, the waterproofing service already had the first element of the Standardized Work tool: a simple standard sequence of activities, shown in Figure 4.

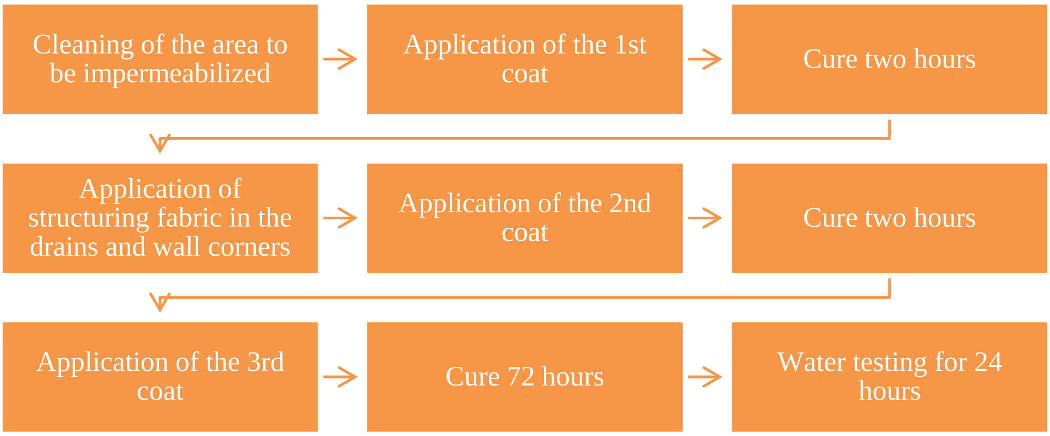

Figure 4– Flowchart of waterproofing service

As shown in the methods section, the study began from monitoring the execution of the service. Thus, it was found that 60% of employee's time was spent on activities that did not add value, such as displacements, cleaning and rework while the remaining 40% were used in the application of the acrylic membrane, in any of its coats. Figures 5 and 6 show the time distribution with activities that added and did not add value to the service.

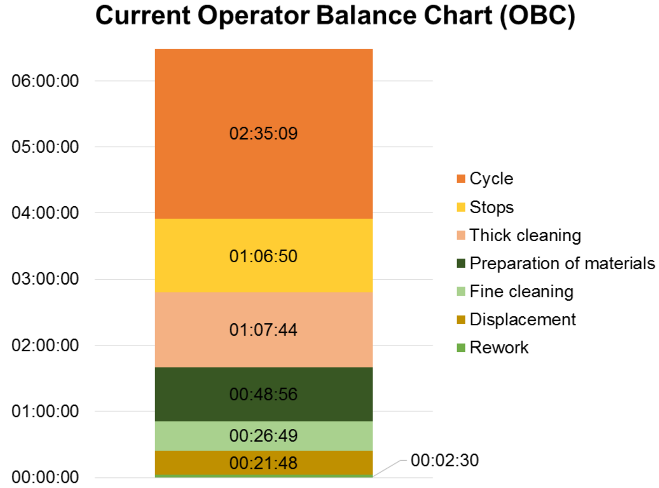

Figure 5 – Current Operator Balance Chart (OBC)

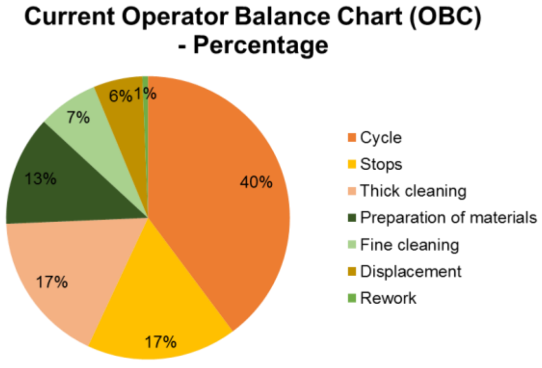

Figure 6 – Current Operator Balance Chart (OBC) - Percentage

Based on this, the first observed improvement point concerned the time spent with stops, which corresponded to 17% of the total. These interruptions were given, in general, by the interference with other services, which sometimes made it difficult for the coat to dry and, in some cases, it was necessary to repeat the application of the membrane. In addition, other rework were also frequent, such when there was any error in installing the ceramic floor, it required the application of the acrylic membrane once again.

Another very critical issue concerned the cleaning of the area to be waterproofed, which should consist only in removing dust with broom or brush, but that, in fact, consisted of a thick cleaning by removing mortar residue and corrections of small failures due to interference with previous services. Thus, this activity consumed 17% of the total time and demanded a lot of physical effort from the employees. It was perceived that the time of thick cleaning could be very minimized if the previous service, which corresponded to the subfloor, left no imperfections in the area.

The analysis also indicated that the time of preparation of materials were considerably long, corresponding to 13% of the total time, once employees did not previously prepare the workstation, which required several displacements along the floor.

In addition, the team had no place to store their tools and equipment, so that they stayed exposed at workstations together with the materials, which sometimes caused theft. It was also observed that the working tools and the personal protective equipment could be more appropriate, as it was the case of the mask and protection glasses used.

Besides the study of distribution of time between the activities that added or did not add value, it was also analyzed the time spent with only the activities of the cycle, in order to determine the minimum time required for the execution of one square meter of the waterproofing system, if the activities that did not add value were eliminated. Thus, Figure 7 summarizes this analysis, corresponding to the future state of the service's execution and comparing the new lowest cycle time with the *takt-time*.

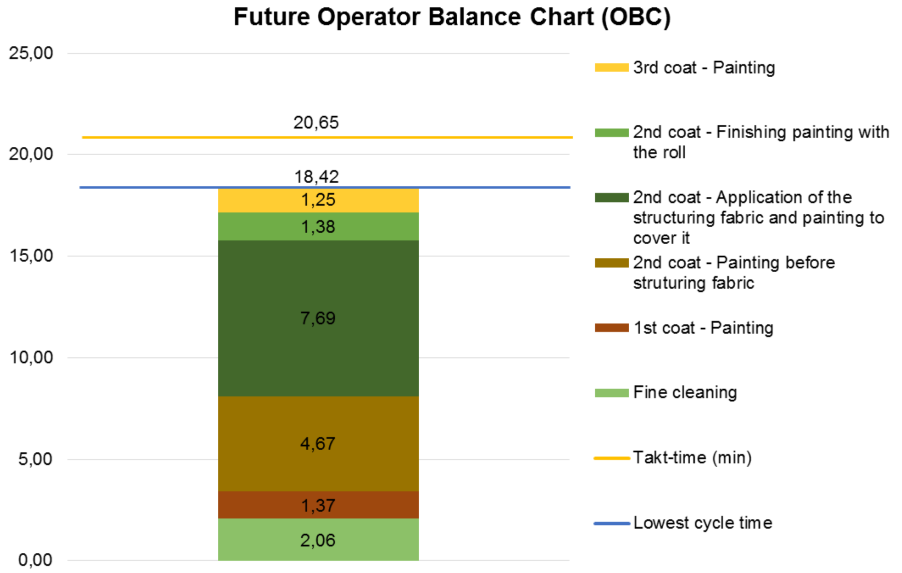

Figure 7 – Future proposed Operator Balance Chart - cycle activities

From all observations, it was defined a new standard sequence of activities that could minimize the amount of activities that do not add value, increase staff productivity and improve the working conditions of employees. All activities were set up in a five-day cycle, enough time to perform the waterproofing of a whole floor (four apartments), as the analysis has shown.

In order to facilitate the understanding of the new sequence of activities by employees, some flash cards of the work routine were developed, which brought the day of the cycle, the shift, times, activities and workplace of each waterproofing service task. Thus, the work team now had pre-established times not only for the inherent activities of sealing itself, but also for the preparation of materials, inspection of future workplaces and resting. In addition, the use of the flash cards was also interesting for controlling the service by supervisors as well as for defining the production rate for employees. Figure 8 shows an example of the flash cards used.

Service: Waterproofing with acrylic membrane		
DAY 2 - TUESDAY		
Morning		
Time	**Task**	**Place**
7h30 – 8h00	Prepare materials for cleaning	2
8h00 – 9h30	Cleaning	2
9h30 – 9h45	Prepare materials for 1st coat	—
9h45 – 11h00	1st coat	2
11h00 – 11h30	Wash the brushes	2

Service: Waterproofing with acrylic membrane		
DAY 2 - TUESDAY		
Afternoon		
Time	**Task**	**Place**
12h30 – 13h00	Prepare materials for 2nd coat	1
13h00 – 14h30	2nd coat	1
14h30– 14h45	Rest	—
14h45 – 15h00	Prepare materials for 2nd coat	2
15h30 – 17h00	2nd coat	2
17h00 – 17h15	Wash the painting roll	—

Figure 8 – Example of standardized work flash cards of for the waterproofing service.

RESULTS

Before the implementation of standardized work, the waterproofing team produced twelve apartments per month, so that the execution cycle of a floor was a little more than seven days. From improvements in the tools and work sequence, the execution of a whole floor has now occurred in five days, so that the monthly production increased to sixteen apartments a month, 33.33% higher than the initial stage.

At first, both workers of the waterproofing team did not seem comfortable with the presence of the research team and with many questions being asked. Nevertheless, the research team was able to identify some dissatisfaction with their tools and equipment, but mostly with frequent rework and other services interference on their activities.

With the daily contact, the waterproofing team gained trust and started to express their opinion about their routine and about the suggestions brought by the research team. After a few days, the work team was fully committed with the new work routine purposed and started to visualize its benefits.

In addition to increased productivity, some qualitative results were also perceived. The first concerns to the improvement of working conditions through the provision of more appropriate tools and personal protective equipment to the team, such as new glasses and masks. In addition, a trunk was provided for storing their tools in order to minimize theft and facilitate transport between rooms and floors.

Another improvement corresponded to the standardized work flash cards, which served as a tool to control and monitor the production. This tool also contributed to the improvement of working conditions, as it has established times for preparation of materials and resting of employees. To ensure that the work team would use the flash cards, every day before the shift starts, the supervisor verifies with his team their daily routine.

In addition, the developed standardized work facilitated the knowledge management of the process, once it documented the standard sequence of execution of activities and allowed the daily monitoring by employees and supervisors.

It was also observed that the auxiliary of the team already had enough skills and knowledge about the execution of the service. Thus, it was requested the promotion of the employee to half-professional, in recognition of a well-done job.

The construction manager, when asked about perceived changes in the process, reported that the Standardized Work has already led to a number of service improvements. The study allowed the perception that small changes can be extremely relevant to the productivity and staff wellbeing. An example of this relates to improvements at workstations, through the provision of better personal protective equipment and most appropriate tools. In addition, the routine flash cards have been very useful for the team and their supervisors, who can monitor more adequately the tasks of each day. Finally, the construction manager considered the Standardized Work of easy replication, so that the study has been carried out with members of the management team and there is the intention to apply it in the execution of other construction services.

CONCLUSIONS

The present paper sought to apply the Standardized Work for the waterproofing service with acrylic membrane. Thus, based on these results, it is believed that the main objective has been accomplished as well as the specific objectives, since the tool was implemented properly and, from that, it was possible to promote improvements in the working conditions of employees, improving the monitoring and execution of service and increased staff productivity.

Given the above, it is believed that innovation is aligned to the current scenario of the second sector. In addition to the contributions to the company of this study case, there are contributions for the construction industry in general, due to the ease of implementation and analysis of the process, and the small demand for material and financial resources.

As Mariz (2012) reports, the application of Standardized Work in the construction industry is still incipient, because there are few studies in this area. Thus, it can be verified the originality of the study not just for the application of Standardized Work itself, but also by focusing on waterproofing service with acrylic membrane, recently implemented in the enterprise.

Another important point concerns the Standardized Work functionality, provided by the work routine flash cards, which help to keep the execution of the service according to the established time and sequence. In addition, the guidance to the production supervision and manager of the construction site provided an assertive process control.

Finally, it is believed that the standardized work is quite affordable in terms of ease of application and financial terms. In the case of implementation, it is demanded only the availability of a professional to monitor the service and perform analysis of activities and times, so that improvements can be realized in a few weeks application. With regard to investment for deployment, it is observed that the costs are negligible, because they correspond only to shopping tools and equipment that are more appropriate and the working hours of the professional responsible for conducting the process of standardized work.

Thus, the application of Standardized Work has brought good results for the company. In addition, the work can be easily replicated for other services, given the simplicity of the analysis and the low demand for material and financial resources. Thus, there is an expectation to perform the Standardized Work with the critical services of the construction site and follow the application in other work packages listed in the line of balance, the main tool for long-term planning of the company.

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SOCIAL NETWORK ANALYSIS FOR CONSTRUCTION SPECIALTY TRADE INTERFERENCE AND WORK PLAN RELIABILITY

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ABSTRACT

Managing of multiple specialty trades working on a large number of interdependent tasks in complex construction projects can be challenging. There are various types of uncertainty associated with construction processes such as prerequisite work, weather, material and labor availability. One of the key uncertainty sources which have not been gained much attention is the specialty trades' (sub-contractors') interference in the construction jobsite during the project. Although the importance of controlling the trades' interference is acknowledged by the construction managers, applicable methods to visualize and analyze them numerically are limited. This paper uses social network analysis (SNA) to examine how the existing interference potential among the specialty trades is related to their work plan reliability (WPR) over the course of the project. It evaluates the consistency between the trades' WPR and the project network characteristics. A 28-week case study involving 43 specialty trades constructing of a single level, $50 million, 14,000 square meter data center was conducted. Primary results show that there is a moderate correlation between the plan percent complete (PPC) and centrality ratio and network density. The findings of this research can help project managers in managing the probable interferences among the working specialty trades and improving their WPR.

KEYWORDS

Social Network Analysis, Centrality, Construction trades, Trade performance, Plan percent complete, PPC.

INTRODUCTION

In the complex environment of construction projects, where there exist series of interdependent tasks and large number of internal and external uncertainties, one challenge to project managers is how to deal with scheduling and sequencing the large number of trades involved (Tavistock, 1966; Pryke, 2012; Wambeke, Liu and

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Hsiang, 2012). Trades usually have to share the limited working space during construction to perform their tasks. When two or more trades work in the same working area at the same time, they could be influenced by each other due to inadequate working spaces or work area access, overcrowded jobsite, prerequisite work, availability of labors, equipment or materials, safety hazards, etc. Without appropriate coordination and cooperation, depending on the level of complexity, productivity can be affected and project completion can be delayed. (Gou, 2002; Thomas, Riley and Sinha, 2006).

There are some project scheduling approaches that can help in identifying and preventing the interference among the trades. For instance, “location-based management system”, which focuses on the project locations to maintain a continuous resource flow throughout the project, considers space availability, and any conflict between trades (Seppänen, 2009). Another example is “Takt Time Planning” approach. It breaks down the project into locations (zones) and sets the rate at which each zone is completed and thereby balances the workflow. In this approach, trades know their working zone and their spot in the trade sequence at any time, so the chance of conflict/interference, due to working in the same spot at the same time, is minimized (Frandson, Berghede and Tommelein, 2013). These approaches prevent clashes among the trades by not allowing the trades to work on the same working spot at the same time and put them in a sequence. However, even though the direct interferences are prevented, there are many situations in large complex construction project that there is a chance of work interruptions between site operations when trades work parallel in the same location (not exactly in the same spot). For example, it is common in large construction project that mechanical and electrical trades perform their task in the same location (like same hall, or floor) at the same time, but different spots (like different room walls). This causes some work difficulties including overcrowded location, inadequate working area access, or distraction, which increase the potential of conflict/interference between the trades.

Specialty trades and their spatial relationships in a construction project can be perceived as a social network and can be investigated via social network analysis (SNA). SNA, introduced by Moreno (1960), has been known as a methodology to determine the conditions of social structures by investigating the interferences, relations and interrelationships of a set of actors (De Nooy, Mrvar and Batagelj, 2005). Understanding the underlying social network of trades can help superintendents to manage the project and maintain the schedule successfully; however, achieving this skill takes years of experience and few superintendents could articulate it (Wambeke, Liu and Hsiang, 2012; 2014).

Although the performance of a construction trade is highly dependent on its spatial relationships with other trades, the importance of the participants, coordination among them and their spatial relationship have not been fully appreciated. Most of the social network studies conducted in the project management research has identified the social network based on communication and information flow among the project teams (for example see Chinowski, Diekmann and Galotti, 2008). In this paper, we examine the underlying jobsite social networks of construction sites from an analytical view. We first investigate how jobsite social networks, representing interference potentials among the trades, are created and modified over the course of a project. We then identify the impact of network characteristics on the trades' work plan reliability (WPR) by exploring the relationship between the plan percent complete (PPC) and social network density (project level) and centrality (trade level).

SOCIAL NETWORK ANALYSIS IN CONSTRUCTION

A social network refers to a pattern of ties that exist among different entities (nodes) such as countries, states, organizations, etc. (Wambeke, Liu and Hsiang, 2012). While classic social network research has concentrated on sociological networks, it has been applied to many research fields (such as aerospace equipment, automotive bodies, and computer and office equipment) with the goal of investigating various relationships among organizations and individuals (Park et al., 2011).

SNA has become important within the engineering and construction field recently due to significant attention to some concepts such as trust and communication between project participants (Chinowski, Diekmann and Galotti, 2008). Wambeke, Liu and Hsiang (2012) believed that an underlying social network of trades exists in a construction project and its recognition can contribute to project success. However, there has been limited research using social networks in the construction projects and most of them focused on the information exchange/communication. For instance, Thorpe and Meade (2001) studied study push/pull communication patterns via SNA. Chinowski, Diekmann and Galotti (2008), using SNA, modelled the information passed through the team members to reduce the uncertainty during construction. Park et al. (2011) investigated the formation and impact of construction firms' collaborative networks for performing international projects, using an SNA approach. Dogan et al. (2013) attempted to assess the coordination performance of a construction project based on the centrality measures of e-mail communication network.

Research pertaining to the jobsite spatial social network, where actors are specialty trades of the project and two trades are connected to each other in the network if they physically work in the same location(s) at the same time, is very limited. Wambeke, Liu and Hsiang (2012) outlined a procedure to identify the organizational social network of construction trades and determine its key members. Wambeke, Liu and Hsiang (2014) implemented a variation analysis in the associated social network of trades to create a decision making system. Abbasian-Hosseini et al. (2014) proposed a social network-based data envelopment analysis (DEA) benchmarking procedure (SDBP), which combines DEA (assessing the relative efficiency of DM units) and SNA to identify the benchmarks for the inefficient specialty trades. The previous research pertaining to the jobsite social network provided decision making tools to show the usefulness of the SNA application, but according to our knowledge, the relationship between the network characteristics and the PPC ratio of the trades has not been studied.

RESEARCH METHODOLOGY

CASE STUDY

A general contractor (GC) overseeing 43 subcontractors, also referred to as trades, involved with the construction of a 14,000 square meter data center participated in the case study. A GC with several subcontractors was chosen for the study because the research is focused at the jobsite social network that exists among the various trades, thus there was a desire for a study a project with more than just a few subcontractors. The $50M project entailed the build-out of an existing warehouse building into a data center and white space computer labs. Construction ran from February through September 2010 and the project was studied from the beginning of March through completion at the end of September. There were nearly 1200 tasks performed by the 43 various trades working on the data center during the course of this 28-week study.

DEVELOPING NETWORKS

A social network generally consists of a set of vertices and ties between them. In this research, the specialty trades are defined as the vertices and the ties among them represent the interference potentials among them in the jobsite. A jobsite social network was built for each of the 28 weeks (Totally 28 networks). The project was divided into 5 main working areas: “Site work Area”, “Lab Area”, “Data Center Area”, “Administrative Area”, and “Exterior Skin & Roof Area”. Any tie connecting two trades in a weekly jobsite social network shows they were working in the same area in that week. We believe that the influence a trade has on another (sending influence) is not as the same as the influence it gets from that (receiving influence). Thus, we used directed reciprocal lines to establish the jobsite social networks. Twenty eight networks representing the 28 weeks of the project were developed. For instance, the social network depicted in Figure 1 shows the interference potentials of the specialty trades in 16th week of the project (Week 16). As can be seen, 17 specialty trades were active during Week 16, that is, they performed tasks in that period of time (23 were inactive, can be seen in the figure caption). The existing ties among the trades indicate that they worked in the same area. The weights of a tie between each two trades are the number of tasks each of them performed in that week, and it actually indicates the influence they sent to each other in that period of time. For example, the weights of 6 and 1 for the tie between the “Fire Protection” and “Painting” trades show that the “Fire Protection” and “Painting” trades performed 6 and 1 tasks respectively in the same area in the Week 16.

It should be noted the tasks performed by various trades may not be equal (there may be different equipment, labors and materials). However, we assumed all the tasks to have the same magnitude of influence in this research, because, the trades in our case project had been asked to breakdown their tasks to the activities with the maximum duration of 1 week and the maximum cost of $10,000. These boundaries/scopes in defining the tasks lighten (if does not eliminate) the inequality impacts of the trades’ operation.

MEASURE NETWORK CHARACTERISTICS

Centrality: “Centrality” measures the relative importance of the vertices within a network. There are various ways to measure the centrality such as degree, betweenness and closeness centralities (De Nooy, Mrvar and Batagelj, 2005). In this paper, we examine the impact of trades on each other, so we used Weighted In-degree Centrality to measure the receiving influences by each trade. Degree centrality of a trade is simply the number of its ties (representing interference potential frequency); in-degree centrality is the number of its incoming (receiving) ties; and so the Weighted In-degree Centrality is the summation of the weight of its incoming ties (interference potential severity). It actually indicates how much influence a trade receives from its neighbors. The more centrality ratio obtained for a trade indicates that there were more tasks have been done by its neighbors in that period of time. For each of the 28 weeks of the project, centrality analysis was conducted and the centrality ratio was calculated for each trade in each week (overall 28 measurements for each trade).

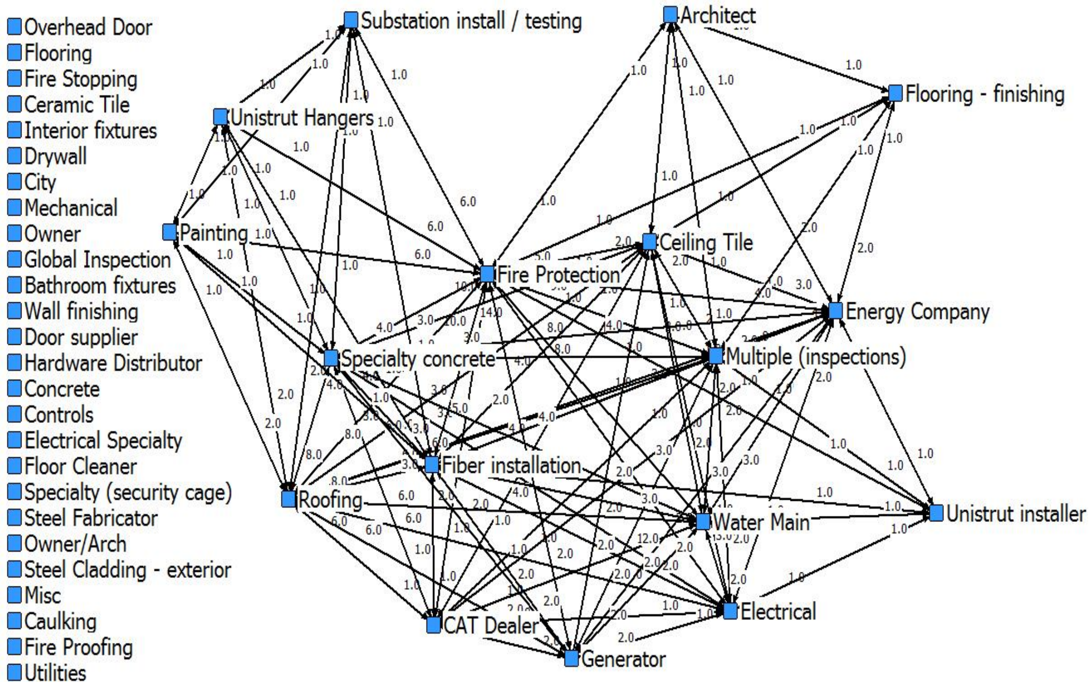

Figure 1: Jobsite Social network of the specialty trades – Week 16

Network Density: The network complexity can be represented by the network density. Network density simply shows how congested a network is. The "network weighted density", was calculated for each of the 28 networks, is the ratio of the sum of the weights of ties versus the maximum possible ties in the network (Liu, Wong and Chua, 2009).

MEASURE PPC

PPC evaluates the difference between what a specialty trade has planned to do and what actually gets done. PPC ratio for each trade in each week was calculated as follows:

$$Plan\ percent\ complete\ (PPC) = \frac{\text{\# tasks 100\% completed}}{Total\ \#\ planned\ tasks} \qquad (1)$$

RELATIONSHIP BETWEEN NETWORK CHARACTERISTICS AND PPC

Correlation analysis was done to evaluate the consistency between 1) Weighted In-degree Centrality and the PPC of the trades (trade level), and 2) Density of the networks and Average weekly PPC of the project (project level).

We used the Kendalls' Tau correlation, which assesses the relationship between any two ordinal variables to see if they are concordant or discordant. Two pairs of rank (x_i, y_i) and (x_j, y_j) are concordant if $(x_i - x_j)(y_i - y_j) > 0$, and discordant if $(x_i - x_j)(y_i - y_j) < 0$. Conceptually, Kendall's *Tau* coefficient is designed to assess the proportion of discrepancy between concordant pairs and discordant pairs, which can be expressed by (Kendall and Gibbons, 1990):

$$Kendall\ \tau = \frac{n_c - n_d}{\frac{n\ (n-1)}{2}} \qquad (2)$$

Considering *n* size of the sample, the total number of possible pairings of *x* with *y* observations is *n(n-1)/2*. n_c and n_d are the number of concordant (ordered in the same way) and discordant (ordered differently) pairs respectively.

RESULTS

RELATIONSHIP BETWEEN CENTRALITY AND PPC (TRADE LEVEL)

Table 1 summarizes the results for the analysis conducted to find the relationship between the trade's centrality and PPC. The analysis was conducted on those trades attended more than 10 weeks (out of 28 weeks) of the project. The number of weeks attended and the total number of tasks are shown in Columns 2 and 3 respectively. Columns 4 and 5 present the average of measured centrality and the average of measured variation. The Kendall Tau coefficient in the last column indicates the consistency between the measured Centrality and PPC for each of the trades. Kendall Tau coefficient can be between 1 and -1. The more positive value shows the more perfect positive correlation and vice versa. As can be seen, the coefficient is negative for almost all the trades. We had expected to not to have a perfect correlation here (i.e. τ close to -1), since this research only consider the uncertainties receiving from the trades' interference. It can be inferred that there is a partial negative correlation between the measured centrality and PPC. In other words, the more centrality (i.e., the more interference potential) a trade has would generally cause the lower ratio of PPC.

Table 1: Summary of analysis: Relationship between Centrality and PPC

	# weeks attended	**Total # tasks**	**Average Weighted In-Degree Centrality**	**Average PPC Ratio**	**Kendall Tau Coefficient**
Ceiling Tile (A)	12	33	0.27	70%	-0.71
Inspections (B)	21	57	0.51	72%	-0.42
Drywall (C)	23	132	0.60	76%	-0.07
Mechanical (D)	27	235	0.85	77%	-0.04
Fire Protection (E)	18	44	0.39	80%	-0.18
Flooring-Finishing	11	21	0.20	71%	-0.58
Wall Finishing (G)	10	22	0.24	64%	-0.49
Electrical (H)	27	200	0.80	72%	+0.02
Roofing (I)	11	22	0.15	77%	-0.39
Concrete (J)	17	51	0.39	75%	-0.25
Controls (K)	14	32	0.30	72%	-0.39
Fiber Installation (L)	16	35	0.27	83%	-0.33
Painting (M)	19	77	0.48	82%	-0.36
Steel Fabricator (N)	17	73	0.27	78%	-0.54

The relationship between the trade's centrality and PPC can be different from one trade to another. It highly depends on the trade's operation type (the type and amount of labor, equipment, space, and material) and the workload (number of tasks and number of weeks attended in the project). For instance, the high level of consistency level for “Ceiling Tile” trade indicates that it suffered more (compare to other trades) from the interferences in the jobsite during the project. It might be because the operations of the ceiling covering cannot be effectively performed when another trade is working in the same locations (it can be easily interrupted by other trades’ activity). On the other hand, lower consistency of the “Electrical” trade shows that the electrical work does not require a lot of space and would suffer less from interference.

Additional analysis was done to find out how the obtained correlation is sensitive to the workload of the trades. Figure 2 shows the relation between the correlation coefficient and the average number of tasks performed per week by the trades (#tasks divided by #weeks attended). Results generally show that the trades with higher average number of tasks per week (large trades) are less sensitive to the jobsite interferences. It might be because they have more flexibility (for example move their workforce from one task to another) to perform their job when they are interrupted by the other trades. On the other hand, since the number of tasks is very limited for the smaller trades, they do not have enough flexibility to stay away from the interference conflicts.

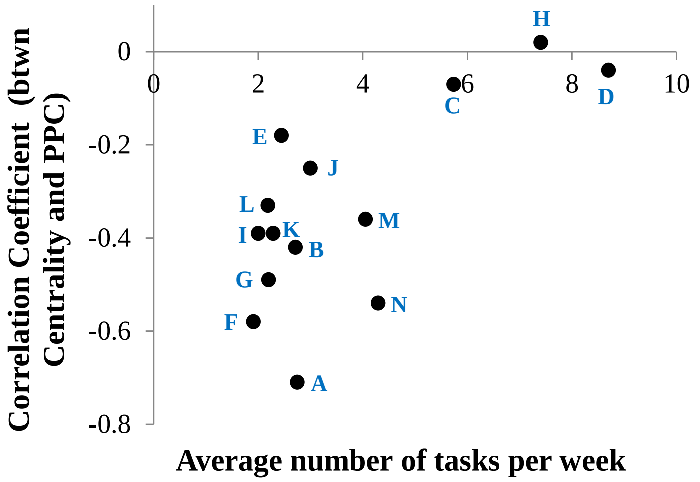

Figure 2: Relation between the correlation coefficient and the average number of tasks performed per week

The case by case examination will help the project management team and site managers to identify the trades suffer more from the jobsite interferences, so they can focus more managerial efforts on these trades to alleviate the impact. The centrality value of a trade indicates how much influence it receives from the jobsite social network. Therefore, the influence of the network on each trade at any time of the project can be predicted based on the centrality values. Then, proper actions can be taken by the site managers or trade leaders with regard to those trades under the strong influence in order to alleviate the impact.

RELATIONSHIP BETWEEN DENSITY AND AVERAGE WEEKLY PPC (PROJECT LEVEL)

Figure 3 depicts the weekly network density and PPC ratio over the course of the project (28 weeks). The network density fluctuates week by week but gradually increases as we go forward in the project until it reaches its peak in the Month 6 (Week 21 to 24). The density decreases in the last two weeks of the project. This trend reflects the workload of a typical construction project. The workload is low at the beginning and then it increases gradually until a few weeks before the project completion. The PPC ratio, ranged from 53 to 94%, had the average of 75%.

Figure 4 shows the relationship between the network density and weekly PPC of the project. There is a significant correlation between the network density and weekly PPC. A correlation coefficient of -0.3 was obtained based on the Kendal Tau correlation analysis. It can be inferred that a moderate negative correlation exists between the network density and the PPC. In other words, the less network density was associated with the higher PPC ratio. It makes sense as the network density represents the volume of the work performed in each week in the jobsite and the less value of the density generally refers to the less interference potential. Thus trades face less interruption in performing their tasks and the PPC increases.

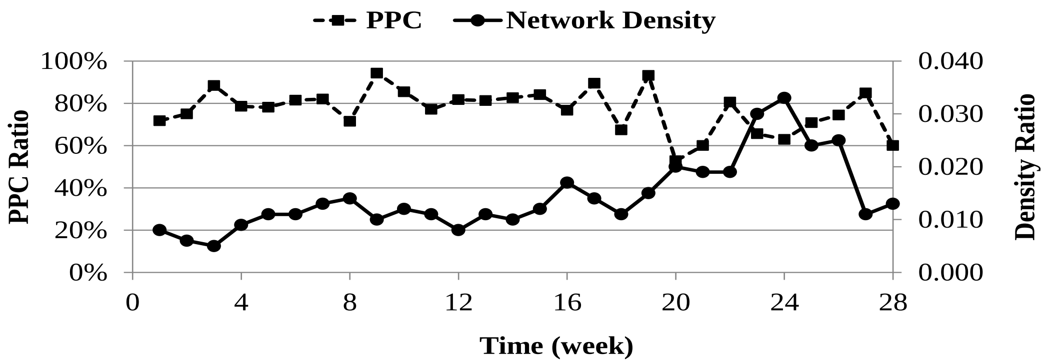

Figure 3: Weekly network density and PPC ratio over the course of the project

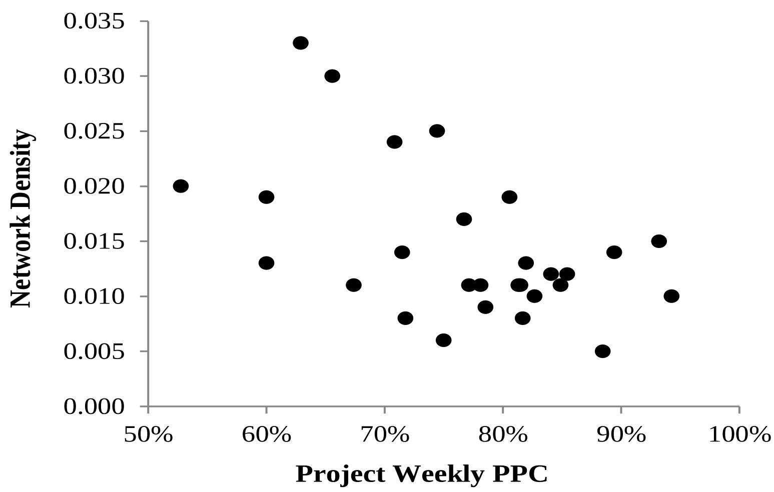

Figure 4: Relationship between weekly network density and PPC ratio

CONCLUSION

Understanding and addressing the role of jobsite interferences in the project will help construction site managers to monitor and control them through better planning and leadership, consequently increase the jobsite productivity. This paper used SNA to examine how the interference potentials among the specialty trades are related to their work plan reliability over the course of the project. It evaluated the Kendall Tau correlation between the trades' PPC and centrality ratio in the existing network. Results showed that the correlation is negative for most of the trades, which means that higher jobsite interference potential is associated with a lower PPC. A significant negative correlation obtained between the network density and the project PPC ratio. The results conform to management practical experience since the more interference potential in the jobsite increase the chance of conflict occurrence.

The value of this research is that it helps the construction project managers to understand the impact of jobsite social network, representing interference potentials, on the work plan reliability through an analytical approach. The process of network development and centrality analysis was explained step by step, so it can be repeated in any project based on the existing work plan. Additionally, the research has the following benefits for the project/construction managers and superintendents:

1) The proposed approach helps the project managers and superintendents to identify the critical trades (those receive more influences from the jobsite social network, i.e., more centrality ratio) and the critical time periods (the weeks with the higher interference potential and complexity, i.e., more density) by quantifying the jobsite social network characteristics. Thus, they can take proper actions to reduce the interference potentials. The jobsite social network for each week can be developed based on the existing work plan of that week before the task execution (in our case, one week ahead). The centrality value of a trade in that week indicates how much influence it is going to receive from the network at that particular time period of the project (in our case, next week). Therefore, the influence of jobsite social network on each trade at any time of the project can be predicted based on the centrality values in advance. Then, in order to alleviate the impact, proper actions can be taken by the site managers or trade leaders with regard to those trades under the strong influence. One common way is to adjust the planned schedule. Easy application of approach enables project managers to run the analysis each time they adjust the plan, so they can select the best alternatives (with the lowest impact on the trades). In some cases where schedule adjustment is not feasible (like performing tasks on the critical path of the schedule), project managers can set extra meeting with the leaders of the critical trades to clarify the difficulties they are going to face and find the best solution to reduce the interferences/conflicts.

2) Although the applicability of the proposed approach was shown for an on-going construction project in this study, it can also be used at the preconstruction stage of the project, i.e., prior to starting the project, where GCs make their work plan/task schedule. GCs can implement this approach to evaluate the developed work plan/task schedule with regard to the jobsite interferences. Therefore, they can adjust the task schedule or modify the work breakdown structure to achieve the schedule with the least interference potentials.

We acknowledge that there may be other factors, in addition to the trades' interference, also affect the trades' work plan reliability in the jobsite; and that makes the obtained partial correlation between the network characteristics and PPC ratio more tangible.

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EXPLORING THE IMPLEMENTATION OF THE LAST PLANNER® SYSTEM THROUGH IGLC COMMUNITY: TWENTY ONE YEARS OF EXPERIENCE

Emmanuel I. Daniel[1], Christine Pasquire[2], and Graham Dickens[3]

ABSTRACT

There is robust evidence that the level of implementation of the Last Planner® System (LPS) is increasing geographically and geometrically in construction. The International Group for Lean Construction (IGLC) community has reported this growth at IGLC conferences over this period. However, no study has explored how the LPS and its implementation has developed or improved.

This study explored developments in the LPS from the review of IGLC conference papers. Qualitative research design utilising content analysis was adopted for this study comprising 57 IGLC reports on LPS implementation across 16 countries. The study reveals components of LPS implemented, with measuring of PPC, Weekly Work Planning meeting and recording reasons for non-completion the most reported. The study developed a timeline for the LPS development and revealed that some of the papers reviewed have no defined methodology.

The study concludes that the LPS has developed in terms of its level of implementation, theory development, and as a vehicle to improve construction management practice across the major continents of the world, with elements that had little presence at the onset now prominent. The study recommends that more attention should be given to the relationship between practical applications and research methods to aid the establishment of sound theory to improve practice.

KEYWORDS

Last Planner® System, implementation, lean construction, IGLC, production control.

INTRODUCTION

The Last Planner® System (LPS) of production control was formally introduced in the construction industry over 21 years ago. Its implementation has gained prominence in recent times and its influence on the production system seems magical

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(LCI, 2015). The LPS developed by Ballard and Howell in 1992 focuses on reducing the uncertainty in workflow overlooked in traditional project management (Ballard and Howell, 2003). Uncertainty or variability in workflow has been identified as a contributory factor to the poor performance of construction projects (Howell and Ballard, 1998; Ballard and Howell, 2003). However, the LPS is an integrated and comprehensive approach that intends to increase predictability and reliability of planned construction activities at the implementation stage on construction site (Mossman, 2014). It is worth noting that its application is not limited to the construction stage alone, as it is also effective at the design stage. More importantly, there are robust evidences that the level of implementation of the LPS is increasing geographically and geometrically in construction (LCI, 2015). Previous studies have reported the implementation of the LPS in building construction, heavy civil engineering construction, highway and infrastructure projects, including ship building and pit mining (Liu and Ballard, 2008; Ballard, 1993) with enormous benefits (Alarcón et al., 2005). However, no study has explored how the LPS and its implementation has developed or improved. Consequently, this study seeks to answer the research question; *"How has the LPS been implemented and developed over its 21 year life?"* The study highlights the major timeline in the LPS development, and examines the trend in the elements of the LPS. The study also reviews the methodologies adopted in LPS implementation.

THE LAST PLANNER SYSTEM

The underlying theories of the LPS revolve around planning, execution, and control. Ballard and Howell (2003) observed that the LPS focuses on planning and production control as opposed to directing and adjusting (cybernetic model) in the traditional project management approach. There are 5 key principles in the LPS which are; (1) ensure tasks are planned in increasing detail the closer the task execution approaches. (2) ensure tasks are planned with those who are to execute them (3) identify constraints to be removed on the planned task beforehand (4) ensure promises made are secure and reliable and (5) continuously learn from failures that occur when executing tasks to prevent future reoccurrence. LPS integrated components include; master plan, collaborative programming or phases planning, make-ready process, production planning, production management and learning (Ballard, 2000; Mossman, 2014). Its implementation supports the development of collaborative relationships among project stakeholders.

RESEARCH METHODOLOGY AND FRAMEWORK

Qualitative research design based on literature review and content analysis was adopted. The framework for the review is based on the approach recommended for content analysis by Berg and Lune (2011) and Robson (2002) as shown in Figure 1. Berg and Lune (2011) assert that content analysis is applicable in any field of human communication such as written documents, audio and video information, and it has been used in various field of learning for research, including construction management research (Jacob, 2010). Content analysis is used in research to achieve the following: (1) identify cultural trend in a group, institution or society (2) show trend in communication contents (3) identify response to communication (4) identify propaganda in information content and (5) show focus in communication by group, institution or society (Weber, 1985). Again, this shows that the choice of content analysis for this study is not only appropriate, but also robust. For instance, in this study, content analysis was used to show trends in the content of communication on the LPS implementation in construction as published by the IGLC between 1993 and 2014. Content analysis enables study to ascertain data reliability when the documents analysed spans over a period of time (Weber, 1985). This implies that the findings from this review would be reliable since the cases analysed span a 21 year period.

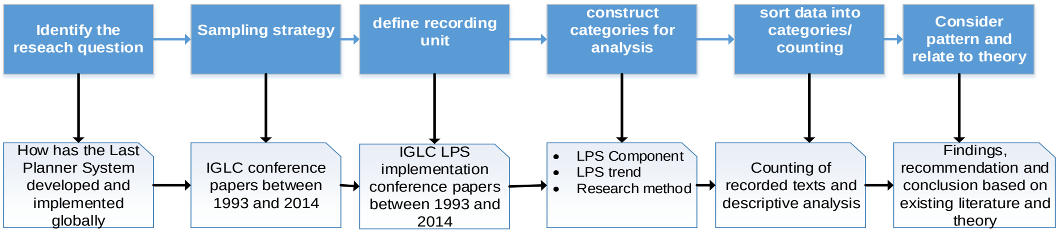

Figure 1: The Review Framework, Adapted after Berg and Lune (2011) and Robson (2002)

The data analysed are the publications of the IGLC annual conferences available at (www.iglc.net), although they are limited to publications that capture LPS implementation in construction between 1993 and 2014. Nevertheless, the study considers the sample appropriate as it has been reported that the IGLC database hosts the majority of publications on the application of lean in construction globally (Jacobs, 2010). The sample was arrived at through reading of the topic and abstracts of various sections and using keyword searches. These include publications from the production planning and control section; the case study and implementation section among others. Keyword searches on the database such as Last Planner System and case study were made in each publication year. This approach was used to avoid omission of papers on LPS implementation. Based on this, a total of 57 publications from 16 countries that reported LPS implementation were retrieved from (www.iglc.net) as shown in Table 1. Of these, 42 reports contained implementation on sites, 4 in design while 11 show no actual implementation. The 42 studies that reported LPS implementation on construction sites were analysed. The selected papers were read thrice, with a focus on obtaining information on the stated objectives. (See link to the reviewed papers https://www.dropbox.com/s/e26b47m4721ren3/IGLC%20LPS%20implementation%20papers%20reviewed.pdf?dl=0). The findings are discussed below.

RESULTS AND DISCUSSIONS

LAST PLANNER SYSTEM IMPLEMENTATION ACROSS COUNTRIES

Table 1 presents a glossary view of the LPS implementation in construction across the globe. The result indicates that the USA recorded the highest number of LPS implementation cases; this is not surprising since the initial concept and its pioneers, Howell and Ballard are based there. This, in addition to the collaboration between the construction industry and centres in institutions of higher learning such as Project Production Systems Laboratory, University of Berkeley (http://p2sl.berkeley.edu/), Lean Construction Institute's (LCI) partnership with contractors and clients in the USA could also have contributed. The study reveals that the uptake of the LPS is not limited to North America alone, as implementation has been reported in almost all the continents of the world. This shows the universal applicability of the LPS; overcoming language and geographical barriers. However, it is worth noting that cultural barriers such as attitude to work could influence the LPS implementation (Johansen and Porter, 2003).

Table 1: Last Planner System implementation across countries

Country	Number of cases
USA	15
Brazil	10
Norway	5
Venezuela	5
UK	4
Chile	4
Korea	3
Nigeria	2
Finland	2
Lebanon	1
Peru	1
Mexico	1
Ecuador	1
India	1
Saudi Arabia	1
New Zealand	1
Total	57

To be specific, Johansen and Porter (2003) reveal from their study that cultural and structural issues among the barriers to LPS implementation in the UK construction industry. These issues include; the blame culture between subcontractors and main contractors, the deep rooted culture that the main contractor should bear all responsibilities. A further examination of the data reveals that South America recorded the highest number of cases of LPS implementation. This could be due to the collaboration between construction companies and research institutions in the area, cum support from active lean construction researchers such as Carlos Formoso (Brazil) and Luis Alarcón (Chile) (Formoso, Tzortzopoulos and Liedtke, 2002; Alarcón et al, 2005).

MAJOR COMPONENTS OF LAST PLANNER SYSTEM IMPLEMENTED

As shown in Figure 2, measuring Percentage Plan Completed (PPC), Weekly Work Planning (WWP) meeting, and recording reasons for non-completion (RNC) are among the commonly implemented components of the LPS in the IGLC papers reviewed. This finding aligns with recent empirical findings such as Dave, Hämäläinen and Koskela (2015) where they observed that WWP was the most commonly implemented LPS element from the evaluation of five projects and a detailed case study. Daniel, Pasquire and Dickens (2015) also observed that phase planning/collaborative programming, PPC measurement and WWP meetings were the most fully implemented LPS elements from their evaluation of 15 construction projects in the UK. The frequent reporting of the measurement of PPC in the studies reviewed seems to show PPC measurement is among the early indicators of LPS implementation in construction.

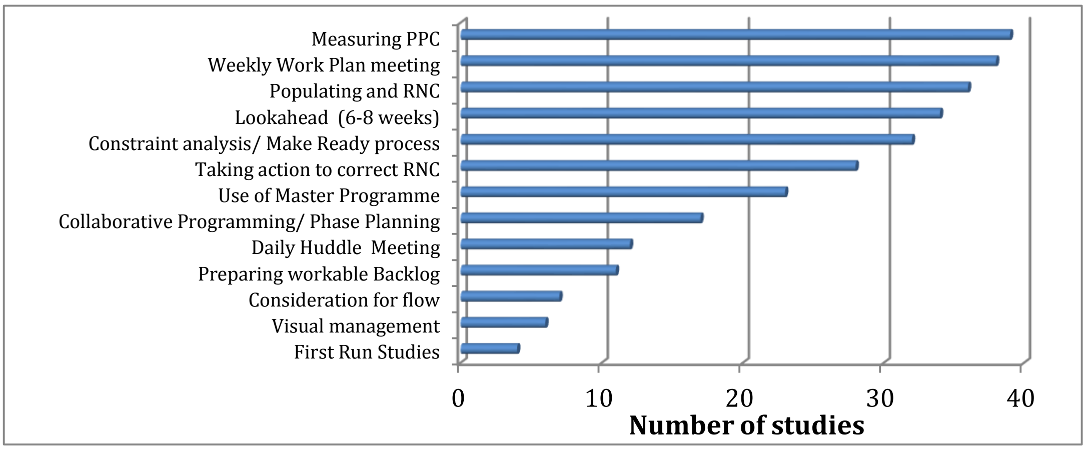

Figure 2: Components of LPS reported in the review

Ballard (2000) asserts that PPC measurement supports continuous improvement as it allows the team to learn from the reasons for non-completion. These are collected at the WWP meetings which is part of the PPC measurement process. This implies that the PPC measurement does not only show plan reliability, but also other project performance indicators such productivity (Liu and Ballard, 2008).

The use of First Run Studies (FRS) and Visual Management (VM) were less reported in the IGLC papers reviewed, even though FRS was among the LPS components implemented as stated in the earlier reports, see Ballard (1993*)*. However, visual management was never described in detail, in the earliest studies on LPS implementation. This could be the reason why VM was less mentioned in the LPS implementation studies reviewed and why lean construction practitioners in the UK construction industry claim that VM is not part of the LPS (Daniel, Pasquire and Dickens, in press). However, when considering the meaning of VM it would seem to be clearly embedded in the LPS system. According to Liff and Posey (2004, pp.1-5), VM is a management approach used to align an organisation's goal, vision, value, and culture in the workplace through visual stimulation of the stakeholders on the project for continuous process improvement. It can be argued that the display of PPC, RNC, magnet planning board, phase scheduling/collaborative planning board and the use of coloured stickies are all part of a visual management system and also part of the LPS.

TRENDS IN THE IMPLEMENTATION OF LPS COMPONENTS

The study reveals that LPS elements reported were not consistent across the years. This could be due to the evolution of the LPS over this time. For instance, phase scheduling/collaborative programming became prominent after year 2000. This could be due to the publication of a white paper by LCI in 2000 to back its use (Ballard, 2000). Furthermore, the study reveals a progressive increase in the use of most of the elements in recent years, as shown in Figure 3, with few exceptions such as workable backlog and FRS. This confirms that the implementation LPS element is growing (LCI, 2015).

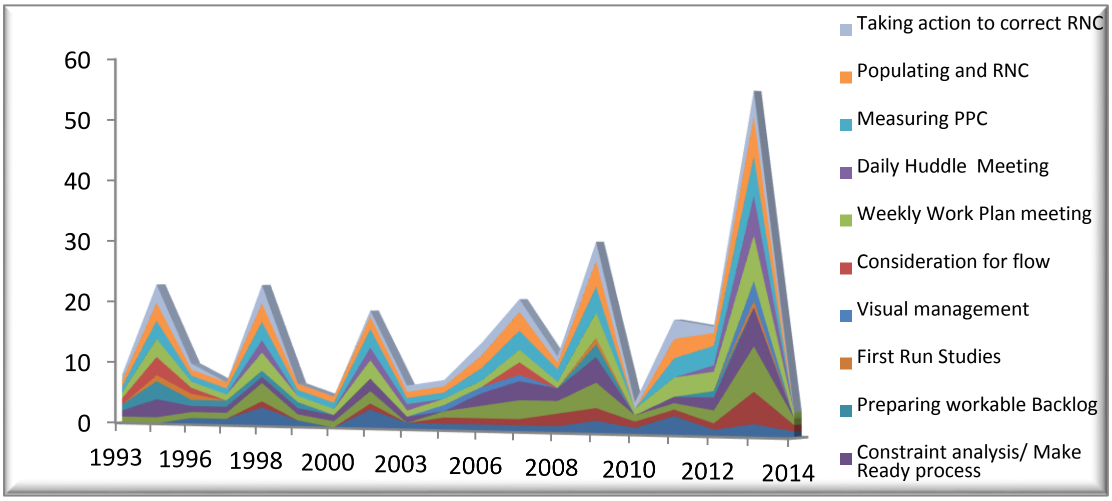

Figure 3: Trend in LPS Elements implemented across the years

However, the extent of the implementation of these reported elements (i.e. in terms of partial or full implementation) still remains an issue to contend as recent empirical studies have shown some of these elements are not fully implemented as claimed. For instance, Dave, Hämäläinen and Koskela (2015) observed from the evaluation of the LPS on five construction projects that lookahead planning was only fully implemented on one out of the five projects. Daniel, Pasquire and Dickens (2015) also observed partial and in some case no evidence of LPS element implementation from their study in the UK. The study also reveals the trend in the use of master programme in developing the phase scheduling or collaborative programme was on the increase over this time. This shows that the LPS has not been totally liberated from the traditional approach of managing construction project. Koskela, Stratton and Koskenvesa (2010) in their attempt to compare the LPS and Critical Chain method (CCM) concluded that both the LPS and CCM were still trading on the traditional critical path method (CPM). However, with the current application of the LPS in design and the emerging concept of Target Value Design (TVD) this can be improved.

EVALUATION OF RESEARCH METHODS USED IN LPS IMPLEMENTATION

Figure 4 indicates that only 35.7% of IGLC papers reviewed have defined research methods. This may be due to the practical application nature of IGLC publications on LPS, coupled with industry papers that merely report case studies with less attention on the scientific methods used in the process. Nevertheless, this should be a point of concern to the IGLC research community that is seeking to build lean construction on sound theories and principles for better practice. Sound theories can only be developed from sound methods and methodologies. Additionally, the review indicates that case study approach was commonly used in the LPS implementation. The use of case study in LPS implementation is inevitable because of the practical nature of the implementation on the construction process. However, case study alone may not be sufficient to generate the needed learning from implementing the process in construction. In view of this, lean construction researchers have called for the use of other forms of proactive research methods such as action and design science research alongside case study (Koskela, 2008).

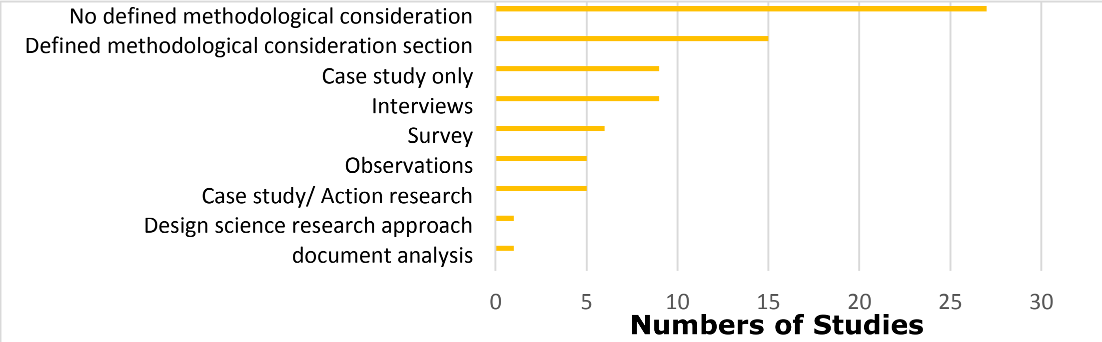

Figure 4: Research methods used in LPS implementation reported in IGLC Conference Papers

THE DEVELOPMENT OF THE LAST PLANNER SYSTEM

The timeline reveals that the concept of the LPS was developed out of consulting work in the industrial construction sector by Glenn Ballard and Gregory Howell (Ballard, 1993; Ballard and Howell, 1998).

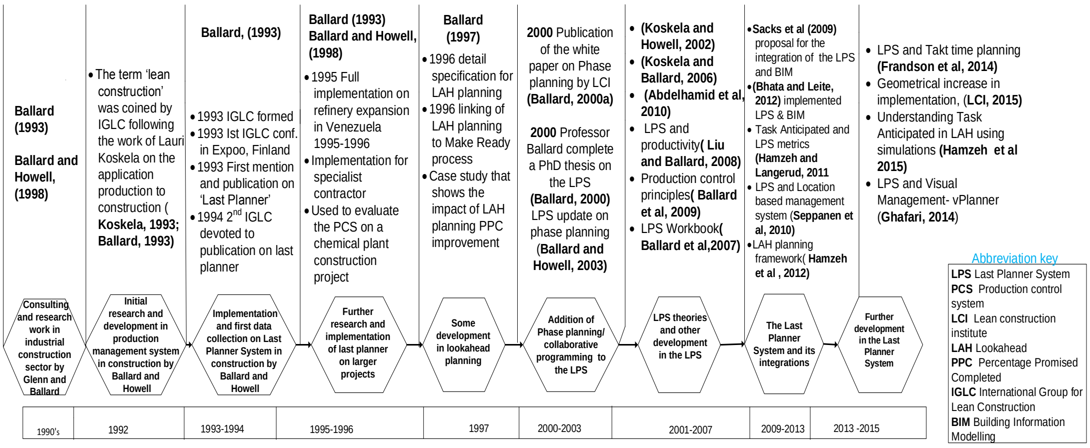

Figure 5: Time line highlighting major developments in the Last Planner System

This shows that the LPS does not originate from the Toyota Production System (TPS) as viewed in some quarters, though its principles align with the TPS. According to Mossman (2014, pp.1-5) the LPS is the production planning and control system developed for the construction industry by construction professionals. The timeline reveals that the initial principles of the LPS are to; improve workflow, improve plan reliability and predictability (Ballard, 1993; Ballard and Howell, 1998; Ballard, 2000). These principles have not changed but have greatly improved through research and practice. Another highpoint in the development of the LPS was Glenn Ballard's PhD thesis on the LPS of production control which happened to be the most referred publication on the LPS. A most recent google scholar search reveals that the publication has been cited 714 times (Google scholar, 13/05/ 2015 at 14:29 hrs). This has initiated various academic researches into the LPS both at masters and PhD levels in various parts of the world. This shows the development of the LPS in terms of research. The further exposition on the underlying theory of the LPS by prominent lean construction scholar such as Koskela, Howell, and Ballard among others brought much understanding on how the LPS works in construction. It is worth to note that the IGLC as a body is committed to developing sound theories for better practice and performance of the construction industry. The LPS is has been evolving, as seen in its integration with other systems such as BIM among others. This is made possible through its robust theory development. Koskela, (2000, pp. 3) state that "*our efforts to develop construction, say through industrialization or information technology, have been hindered by the lack of a theory*". This further magnifies the importance of development of theories for the LPS and lean construction in general.

CONCLUSIONS

The aim of this study is to explore the developments and implementations of the LPS from the IGLC community. The study established that the LPS was developed out of consulting work in the industrial construction sector. The system was specifically developed for the construction industry by construction practitioners to minimise uncertainty in the production process and not from the TPS concept as claimed in some quarters. The study confirms that the LPS is not static, but rather dynamic and has evolved positively over the last 21 years. It reflects this in its ongoing researches in different parts of the world, development of theory to explain current practice and its successful integration with other systems such as BIM, Takt time planning, and Visual Management planning software such as vplanner®.

The study reveals that measuring of PPC, having WWP meeting and populating RNC were among the common components of the LPS reported in the papers reviewed. However, practices such as developing workable backlog and FRS were less reported even though they were part of the initial element of the LPS. The study concludes that the LPS has developed in terms of its level of implementation, theory development, and as a vehicle to improve construction management practice across the major continents of the world.

ACKNOWLEDGEMENTS

The authors are thankful to Prof Glenn Ballard for his review of the LPS Timeline shown in Figure 5.

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WIP DESIGN IN A CONSTRUCTION PROJECT USING TAKT TIME PLANNING

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ABSTRACT

Work in process (WIP) is a well understood and used metric in the management of manufacturing processes. However, this is not the case when it comes to production planning in non-repetitive construction projects. Moreover, there are different understandings of WIP depending on the management personnel using it (financial managers vs. production planners for example). The aim of this paper is to study how WIP can be defined in the context of a construction project so that it can easily be identified, visualized, and managed without having to resort to simulation models or advanced software tools. The authors present a case study where Takt time thinking is used to identify and handle different types of WIP and improve construction workflow. The challenge is to minimize both 'work waiting on workers' and 'workers waiting on work' by determining suitable work area sizes, and having an adequate work backlog. The case study shows how in some cases, areas are separated and sized so that WIP between tasks can be reduced, and in others so that WIP can be maintained as a buffer because reducing it is less of a concern.

KEYWORDS

Takt time planning, WIP, production system design.

INTRODUCTION

Work in process (WIP) is often neglected as a design parameter in the construction industry. Due to the recent increase in the popularity of location based schedule representations (mainly in the Lean Construction community), excessive WIP in construction projects has become more visible to planners and as a result the issue has become more evident. This paper addresses the problem by first defining WIP and introducing the theory behind the concept, then discussing how it can be applied to construction projects. The authors draw support from previous research done about WIP in construction projects and how it is managed. Then, in an attempt to fill the gap found in the literature, the authors propose a less technical but more visual and

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practical WIP management methodology. A case study project using Takt time planning (TTP), the Last Planner System™ (LPS), and careful WIP management is used as an example to show how the methodology is applied on a large scale hospital project in California.

WHAT IS WIP?

As the name suggests, any unfinished work (or area not being worked on) falling between the start and end points of a production routing is considered WIP (Little, 2011). In manufacturing and assembly line production, Little's Law for queueing systems expresses WIP as a function of the cycle time (CT) and the throughput rate (TH). The law says that the average number of units in a queue (WIP) is equal to the product of the average processing time and the average arrival rate (Little, 2011). Thus:

$$WIP = TH.CT \tag{1}$$

In the field of construction management, this concept is currently applied by financial managers, real estate developers, and house building contractors to determine how many projects to start in a given time period (Wardell, 2003). In this case, WIP is the number or houses (or projects) under construction, the processing time is the average house completion time, and the number of house starts is the average arrival rate (Gharaie, Blismas and Wakefield, 2012). Managers can determine how many projects to start in a given time period so that the company can achieve an even-flow production.

However, this method of computing and managing WIP is too high level when the goal is optimizing the construction of a single non-repetitive project and reducing waste in the process. This goal can be achieved by first representing construction schedules in a way that enables construction planners to identify WIP, and then integrating WIP (and the duration for which it stays as WIP) as an additional management parameter in the construction production system design.

WHY IS WIP ABUNDANT IN CONSTRUCTION PROJECTS?

The problem outlined by many before (Koskela, 1992; Ballard et al., 2001; Arbulu 2006 and others) is that production system design is generally neglected in the construction industry. According to Tommelein (1998) and Arbulu (2006), different construction teams refer to the construction schedule and "push" their production accordingly without having some sort of feedback mechanism between the interdependent parties. Because the production rates of each party are different and variable, this eventually results in large amounts of WIP between the handoffs. This leads to lost time, tied up capital, and an increased chance of having damaged work before the next trade moves in. The solutions illustrated by Tommelein (1998) and Arbulu (2006) consist of moving from "push" scheduling systems to "pull" driven scheduling or using CONWIP systems to limit the amount of WIP that can be accumulated between stations. The authors believe that one of the main reasons behind excess WIP in construction projects is the fact that, when the critical path method (CPM) schedule is used to push the production, it is easy for planners to overlook WIP and perhaps perceive the duration for which it exists as a desirable "float" in their schedule. In this case, management does not identify where WIP is occurring or may even treat it as a desired feature. Therefore, it is important that construction planners are easily able to identify and visualize WIP so that they can plan accordingly.

IDENTIFYING WIP IN A CONSTRUCTION PROJECT

Previous research has focused on WIP design and management methodologies for repetitive projects through discrete event simulation modelling (González, Alarcón and Gazmuri, 2006) or by using Rational Commitment Model (RCM) equations (González et al., 2008). This paper discusses how WIP can be identified and managed when the use of simulation tools is not practical, and a more visual and less technical method is required.

In order to design WIP for a production system we must first define the different types of WIP that can be analysed depending on the adopted perspective:

- **WIP for consecutive tasks:** In this case, WIP can be separated into two categories:
  1) WIP within handoffs also known as the production batch, this type of WIP can be used as a design parameter when balancing work between trades. It is closely tied with the methodology of the work done within a trade's scope. It is the minimum possible transfer batch. Refer to Figure 1 for an example of how the methodology affects the production batch size.

  2) WIP between handoffs also known as the transfer batch, this type of WIP is related to whether the unfinished product is handed off to the next task right after the first task is competed, or if there is a waiting time or buffer between the two tasks (Figure 2). In many cases this WIP is a product of not levelling the workflow between processing stations (eg. framer needs 5 weeks to finish Level 2 but plumber needs 7 weeks)
- **WIP in the supply chain:** In this case, WIP is measured by the amount of unprocessed off-site manufactured units specifically for each trade (e.g. rebar, prefab components, etc.) between each of the production phases such as procurement, fabrication, assembly, delivery, material stocking, and installation (Arbulu, 2006). As the team is striving to align all these phases to production areas, we realize the importance of sequencing all these phases to production plan. For example, it is not reasonable to deliver Area 3 material before Area 2 material when the intent is to work on Area 2 before Area 3. The just-in-time (JIT) concept is followed with conscious sizing of WIP.
- **WIP for construction phases:** When using different planning methods but especially location based management system (LBMS) and Takt time planning, the plan is usually developed phase by phase (e.g., Foundations & Shoring Phase, Exterior Phase, Interior High Overhead MEP Phase, Interior Framing Phase etc.) for practical purposes. In our experience, due to the different types of work, different phases can have different area structures to which the work is controlled. In order to minimize waste, creating area structures so that the transition from one area structure to another creates the

least possible amount of WIP is important. With unthoughtful planning the team can increase the project's duration and not gain any value from this.

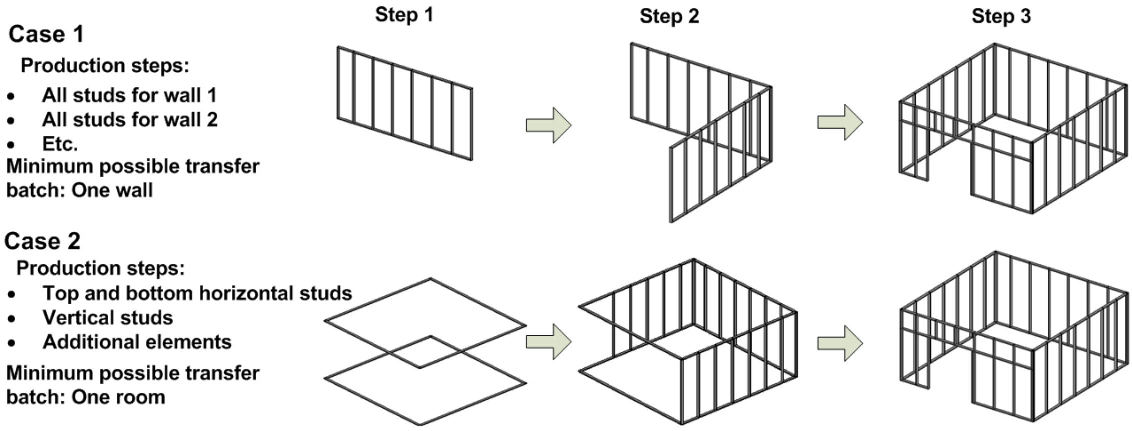

Figure 1: The work process of installing the studs for a drywall in a room affects the possible amount of WIP within a handoff

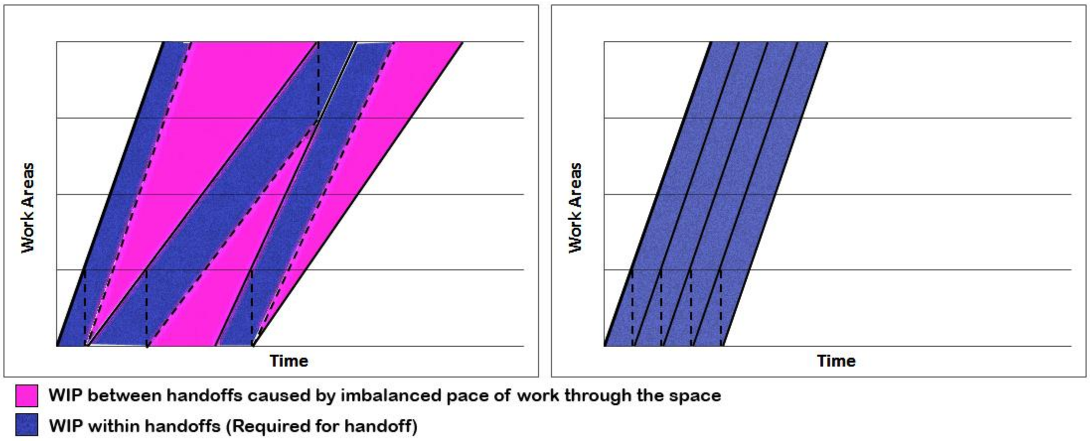

Figure 2: Graphic representation of WIP between handoffs vs. WIP within handoffs. The right graph shows the most efficient scenario where all WIP between handoffs is eliminated by making the production rates for all tasks equal.

CASE STUDY: DESIGNING WIP FOR A CONSTRUCTION PROJECT

OVERVIEW

The case study project is a 7 story, 21,300 square meters acute care hospital project in California. The project site is located in the middle of a busy city and on an existing hospital campus. The Last Planner System® (LPS) is used to its full extent as the team believes that it is the right approach to increase commitment reliability, measure and improve percent plan complete (PPC), and achieve several other values. However, in order to better optimize the design of the production system and obtain a more continuous flow for the majority of trades, the team has added additional layers of planning and WIP analysis to the usual LPS methodology (Figure 3).

Figure 3 is a visual that is displayed on the project planning wall so that employees and visitors are familiar with the planning phases. All levels of LPS are covered (incl. constraint removal, make-ready work, analysing metrics, etc.). The phase “Production Optimization” is added as a transition step between the phase planning phase and the lookahead planning phase. During this phase, the production team works collaboratively with trades to figure out improvement opportunities and develop a Takt time plan before getting to the make-ready lookahead planning phase.

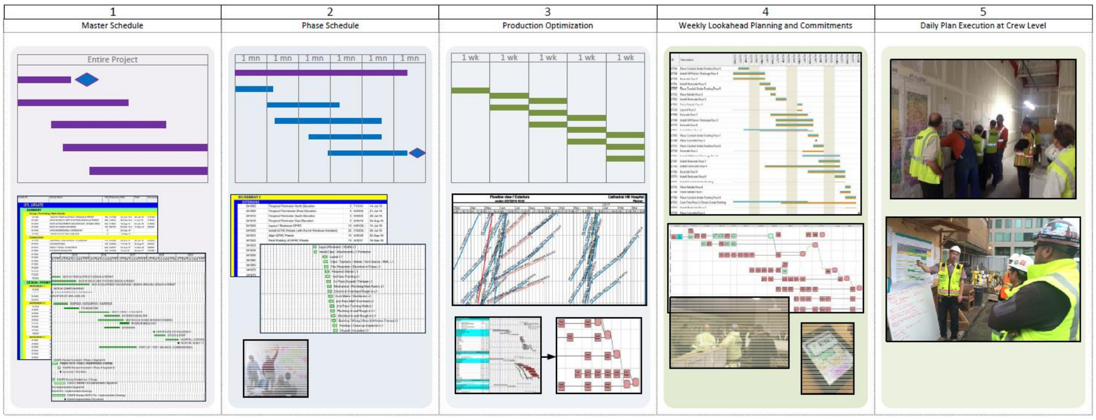

Figure 3: Visual that team uses to explain different levels of planning.

The team’s experience has led them to conclude that traditional schedule representations, such as CPM diagrams and Gantt Charts, make it hard to identify and manage WIP. The LPS adds value as planning is done collaboratively in phases, constraints are removed (work is “made ready”), and the reliability of the plan is increased with last planner’s weekly or daily reliable commitments. However whether the production plan is well optimized or not, is not addressed by the LPS. Therefore additional planning steps that specifically address the management of WIP are needed in order to get the full benefits. WIP needs to be studied for the project as a whole and the team cannot afford leaving its management to each trade leader or area superintendent independently.

Takt time planning is a main component of the ‘production optimization’ phase in our case study project. The following section explains the Takt time planning process and how it is used in the case study project.

TAKT TIME PLANNING

Takt time planning uses a location-breakdown structure with the objective to make work flow continuously. It is designed to have a sequence of trades working in pre-defined areas using the same amount of time (Takt time) in each area. In order to design a Takt time plan the sequence of trades and their activities is designed by a collaborative pull plan, data is gathered to understand crew sizes and durations planned by trades, and all the transfer batch cycle times in a phase are set the same (Frandson, Seppänen and Tommelein, in press). In the case study project, the Takt time is 5 days. As a concept, Takt time planning can be used to reduce WIP both between hand-offs and for each trade. But Takt time planning also aligns procurement, fabrication, and supply flow closely to the plan to reduce WIP in the supply chain. This can be done until the desired project throughput is reached without having to incur excessive costs. The Takt time concept from manufacturing suggests that the priority needs to be work flowing continuously, without stopping; i.e., the priority is avoiding ‘work waiting on workers’ (Linnik, Berghede and Ballard, 2013). This paper again emphasizes that the focus of the process is the same. Linnik, Berghede and Ballard (2013) offer a more elaborate description of the Takt time planning process. Therefore, only a brief explanation is given in this paper due to length requirements.

During the 'production optimization' phase, the planning team deals with two different types of work: 1) Work that can easily be planned in the Takt time strategy because it is relatively easy to balance the workflow among the different trades (which includes the majority of the work on the project) and 2) work in parts of an area (operating rooms, kitchens, etc.) where the work "density" makes it difficult to allocate under the regular sequence (the amount of onsite labor is significantly out of balance with the amount for other crews or other areas of the same floor).

WIP BETWEEN HANDOFFS (INSIDE ONE PHASE OF WORK)

The majority of activities for the case study project are planned using Takt time planning. The production team will have a collaborative pull planning session to define the high level sequence for one phase of work. Also, each trade will submit building plan "color-ups" that indicate how they are planning to work through a certain space (e.g., Level 2), and their crew size. The production team will analyse the pull plan and color-up information, work with trades to develop an area structure for the phase and balance everyone's labor count (Figure 4).

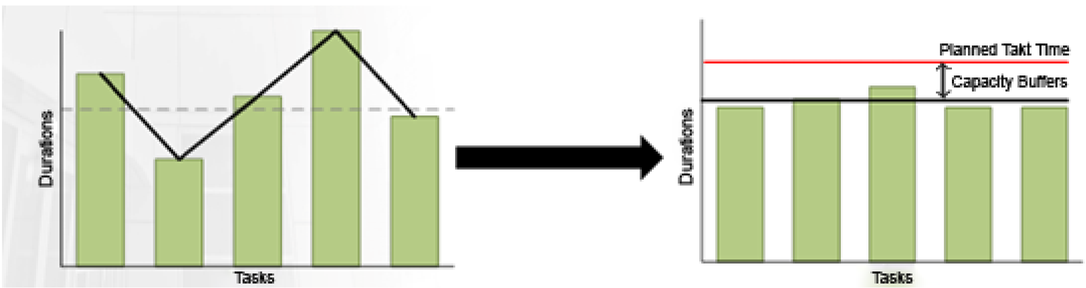

Figure 4: First, the task durations for different trades are not equal. In order to create a Takt time plan, trades are asked to modify their work methods (e.g., more prefab) or crew size to match the Takt time (defined work cycle time) in each area.

Usually the result of this approach is no trade stacking, reduced manpower on site, reduced Phase duration and minimal WIP between handoffs inside the phase. Figure 5 illustrates an example Takt time phase.

By balancing manpower as shown with Figure 5, WIP is minimized between consecutive tasks (e.g., red task and yellow task). The methodology for this type of planning is to find the bottleneck trade in the sequence, work collaboratively to make them faster and then match all the other trades pace to bottleneck trade. The idea is that any trade working faster than the bottleneck trade is not adding value but only creating additional WIP for the project.

This method of planning doesn't require advanced analysis tools, and can be done easily in Excel or even just drafting the flow on a piece of paper. It just requires awareness and understanding of the concept.

The team is using visual representations as shown in Figure 6 (SOG stands for slab on grade) to analyse WIP, see if there is continuous flow for each trade, check for crew idle times (labelled (1) in Figure 6), and examine overlaps where the crew is shown to be working in two areas at same time (labelled (2) is Figure 6).

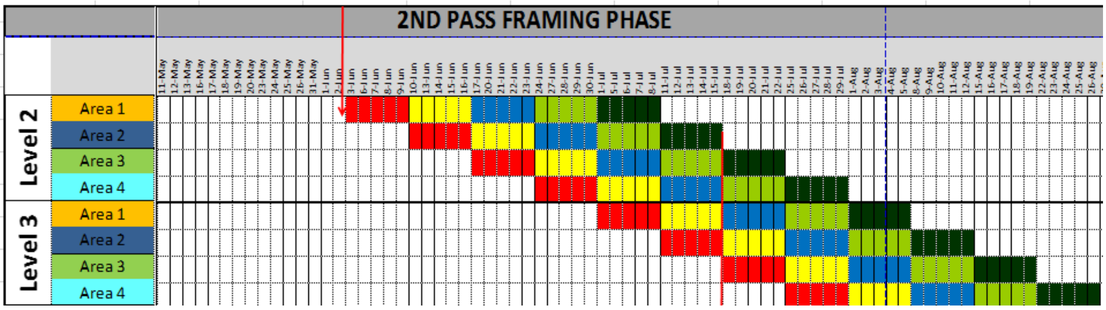

Figure 5: 2nd and 3rd floor of 2nd Pass Framing Phase. Each color represents a specific trade's scope of work in that phase.

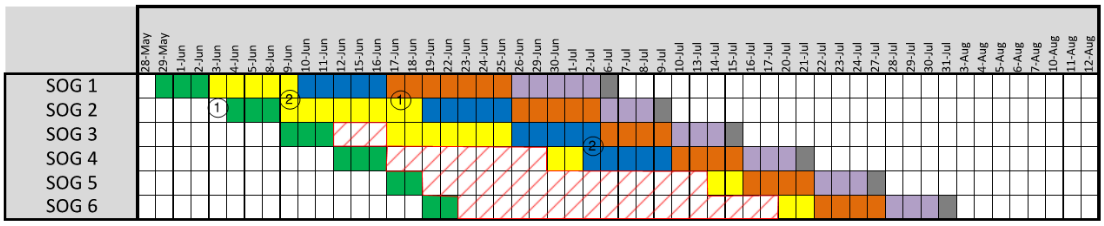

Figure 6: Graphic representation of WIP for work areas Dates are on x-axis, area structures on y-axis, different tasks are represented with different colors, and WIP is shown with the hatch

WIP BETWEEN PHASES OF WORK

Different phases of work may require different area structures because of the differences in work methodologies. For example the overhead MEP scope requires larger areas to accommodate installation and testing of their racks and other components than the framing and in-wall trades require. The team is carefully examining transitions between phases, as different cycle times per phase can result in large amounts of WIP. The team analysed inter-phase WIP for three interior phases and developed four different scenarios for a collaborative discussion and review. Figure 7 shows the original plan for these phases and Figure 8 shows the strategy that the team chose. As a result of this analysis the team saved 5 weeks out of the original schedule while reducing manpower on site, levelling out crew sizes, and reducing WIP between phases. The scenario shown in Figure 7 was considered the better option (25 vs 30 days during which an area is considered WIP on level 7) before the third phase was included in the planning window. However, when the three phases were studied together, it became clear that the scenario shown in Figure 8 was the best in terms of minimizing overall waiting (duration during which there is WIP between phases) in the system (Figure 8).

It can be seen from figures 2, 5, 6, 7 and 8 that a simple change in how the plan is visualized, i.e. using flow lines instead of traditional Gantt charts or critical path method (CPM) network diagrams, easily makes the planner aware of different types of WIP in the system and their quantities. Figures 5, 6, and 7 show a flow line schedule representation method that also integrates some of the features of a traditional Gantt chart and is extensively used by the production team in the case study project.

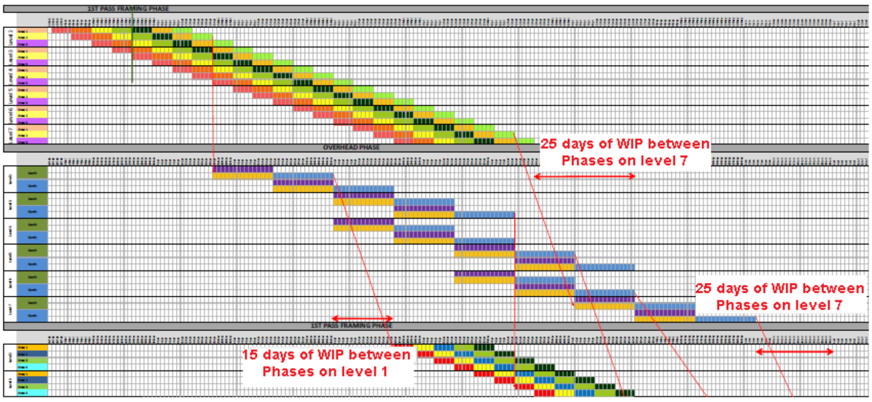

Figure 7: Original Plan for three phases of interior work (1st pass framing, overhead phase, 2nd Pass Framing Phase). Overhead phase is taking place at two floors simultaniously to release work for 1st pass framing phase that has a shorter cycle time. WIP discovered in several areas through simple analysis.

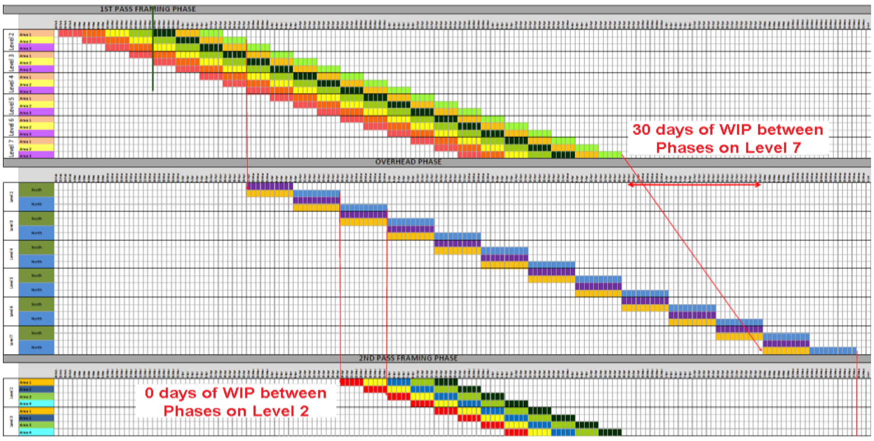

Figure 8: Best choice of suggested 4 options for three Phases of interior work (1st pass framing, overhead phase, 2nd Pass Framing Phase). WIP reduced based on team collaboration and 5 weeks of time saved compared to original plan.

WIP INSIDE HANDOFFS

The optimum handoff size can be different for different phases. The larger the area (in terms of square meters or worker days) one trade is handing off to next trade the more WIP there is in the handoff itself (bigger transfer batch). The team has found that a 5 day handoff period is the most convenient for the case study project and has delineated the work zones accordingly. While this may be increasing the amount of WIP inside handoffs, the team has decided that it (1) provides the amount of flexibility needed to keep the plan reliable and (2) sets a standard duration so that handoff dates and durations are not constantly changing as the project progresses. For many trades, the production team has to fully understand the scope of the work, the adopted process, and the effect of crew size on production rate before determining the area size. Most importantly, the crew has to be completely done with their area before handing it off to another crew by the end of their Takt time production duration (5 days in this case). Though it may sometimes seem that this 5 day Takt is creating unnecessary WIP, the team has found that it has led to great reductions to both overall WIP and project duration when compared to traditional planning methods. Crews know that they will always be working on a structured area for 5 days undisturbed before having to hand it off, and therefore do not have to account for unexpected interruptions by other trades in their plans and increase their contingencies.

WIP IN THE SUPPLY CHAIN

The team is minimizing WIP in the supply chain by aligning the whole delivery system to the designed Takt time strategy. In other words, if material for Area 1 is needed first then the fabrication or kitting for Area 1 is done first. Delivery rules to the site demand that deliveries have to: follow the order of the production strategy, arrive on site in batches containing one structured area worth of material, and be labelled to match with the area structure. Deliveries to the site originally come from either the fabrication facility or third party vendors. In order to deal with the variability that could come from these sources and make sure the delivery rules are applied, the team makes use of the nearby project warehouse. This ensures that a just-in-time pull delivery system can be implemented on site without disturbing the production processes of the fabrication facility or third party vendors. In addition, the production team cooperates with some of the key suppliers to synchronize fabrication to the pull of the project.

CONCLUSIONS

This paper discusses a method of managing WIP in a construction project using Takt time planning. The authors emphasize the importance of using an adequate visual representation of the production plan so that WIP becomes more evident and planners become more aware of the problem. The preferred schedule representation in the case study project consists of a table-based flow line chart using Excel spreadsheet format that also resembles a traditional Gantt chart so that it is more familiar to construction personnel. The purpose of managing WIP in construction projects is to minimize both ‘work waiting on workers’ and ‘workers waiting on work’. In practice, it is difficult to simultaneously minimize these two types of waste and planners often have to minimize one at the expense of minimizing the other. The authors treat minimizing ‘work waiting on workers’ as a priority because they believe it has led to better results in their previous projects and current case study project as well. Until the two types of waste are eliminated, workers waiting on work can perhaps use their time to take care of their workable backlog, or more importantly, study how their process can be improved for the rest of the project. In this way, the team gets the opportunity to minimize yet another type of waste which is ‘unused employee creativity’. In contrast, work waiting on workers does not leave any opportunities for workers to think about their process and come up with ways to improve their plans and processes because they are too busy catching up. In addition there is an increased risk of damage to trade work and tied up capital. Having a constant handoff duration (Takt time) as the project progresses may introduce extra WIP and ‘work waiting on workers’ in some parts of the project where work is easier for some trades. However, the benefits of having a simple and predictable schedule where crews always know that they can work uninterrupted in a structured area for a given duration before handing it off and moving to the next possibly outweigh the disadvantages. By using the methods described in the paper the team has been able to minimize different types of WIP and thereby achieve an estimated 20% compression of the initial schedule. In addition to this, there is added value in making the process very simple to understand for all team members. By making all the participants in the production aware of WIP and how it should be managed so that the whole project benefits, it has become easier for the team to plan and coordinate with the different trades.

ACKNOWLEDGMENTS

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IMPROVING INTEGRATED PLANNING FOR OFFSHORE O&M PROJECTS WITH LAST PLANNER® PRINCIPLES

Adam G. Frandson[1] and Iris D. Tommelein[2]

ABSTRACT

The operation and maintenance of offshore energy projects requires careful planning across multiple time horizons, business units, and companies. Integrated Planning and Logistics (IPL) is a system used to help meet this requirement. This research compares an IPL system in use, as well as existing literature, with a mature planning artifact in construction, namely the Last Planner® System (LPS). The research hypothesis was that implementing Last Planner principles could improve IPL system performance. Despite the challenging environmental conditions inherent to offshore work, data from 30 projects revealed that over 90% of not successfully completed activities failed due to causes related to ineffective planning. Research findings indicate that it would be beneficial to include Last Planner® principles in IPL systems. This paper concludes by presenting a hypothesis to test during further deployment of IPL systems on current or new projects.

KEYWORDS

Last Planner® System, Production management, Operation Planning, Integrated Planning and Logistics

INTRODUCTION

Offshore energy (oil and gas) projects require input from thousands of people across different companies, business units, and fields of expertise. With operating expenses up to and over a million dollars a day, there is a high demand to create clear and effective planning systems that can help to maintain the offshore platforms. Integrated Planning and Logistics (IPL) is a system developed through the Integrated Operations (IO) Center, a collaboration between industry and Norges teknisk-naturvitenskapelige universitet i Trondheim (NTNU) in order to facilitate integrated operations (Ramstad, Halvorsen and Holte, 2013). Though the concept of IPL has been developing since 2004, some projects using it still report low plan attainment percentages during the execution phase of operations.

The research question addressed in this paper was: How can principles from the Last Planner® System (LPS), a system initially used in construction, improve IPL

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during operations? The research uses a design science methodology to compare the two planning systems. In design science, artifacts are constructed and tested in order to solve practical problems and generate theory (March and Smith, 1995). First, this paper presents a background of design science research. Second, the two planning systems are introduced and described. Third, data from current projects using IPL are presented in order understand the current state and identify why activities are missed on the execution plan. Fourth, the paper assesses what plan failures occur that the LPS has been designed and tested to avoid or eliminate. Finally, the paper presents a hypothesis to test, provided the changes to IPL are made.

BACKGROUND

RESEARCH METHODOLOGY & DESIGN SCIENCE

March and Smith (1995) described three modes of producing knowledge. Natural science produces theory that explains the causal relationships in the world. Social science describes human behaviour and other social phenomena. Design science is bases itself on prescription and the creation of artifacts and subsequent testing thereof. While similar to case study research, design science is different because the aim of case study research is not necessarily to prescribe. Benefits to using design science are that it creates practical solutions, generates new theory, and narrows the gap between practice and research.

There are four sequential research activities when conducting design science research (March and Smith, 1995). (1) Building the artifact – Constructing an artifact to fit a specific purpose. (2) Evaluating the artifact – How well does it work? (3) Theorizing - Explain why does it work or not work? (4) Justifying – What evidence is there to indicate this conclusion?

Building the artifact starts with descriptive research in order to understand the environment and the problem. Evaluating the performance of the artifact is based on a specific environment and builds further understanding of the problem, generates knowledge for how to improve the solution, and also helps produce more generalized knowledge on the system itself. One risk in design science is over generalizing the benefits of an artifact, so it is important to clearly communicate the specific environment in which the artifact was tested in. Last, design and evaluation activities are practice focused, whereas theorizing and justification are theory focused.

Design science research is cyclical in nature, for the artifacts change over time due to increased problem understanding and the knowledge gained from testing the artifact. In addition, the phase an artifact is in builds environmental context. The environmental context of an artifact is important to understand because an artifact may solve one practical problem in one environment well, but may have unforeseen consequences when it is introduced into another.

Instead of constructing new artifacts, this research first provides background on two existing ones, IPL and the LPS. The artifacts being compared are these two planning systems. The results section evaluates activity misses that occurred in the course of using an IPL system on 30 projects. Based on the data, the researchers theorized why activities were being missed during and hypothesize that changing current planning practice may be beneficial. Justification for this change is given by looking at a case where practices were already adjusted.

INTEGRATED PLANNING AND LOGISTICS (IPL)

The research was conducted in the course of a 6-month internship with a company. According to company documentation, the objective of IPL is to "facilitate safe and efficient development and production of oil and gas". One reason for implementing the system is to address the problem of siloed planning that is departments plan in their own domain but do not have a systematic way of interacting with departments planning in other domains. Integrating the plans of different departments should facilitate the allocation of scarce resources (e.g., time, locations, materials; tools). This in turn should allow for optimized synergies, reduced risk of schedule clashes, improved prioritization of planned work, increased trust in plans, greater reliability of plans, opportunity for the organization to learn, and allow for plans to contain details of sufficient and constant quality.

Figure 1 reflects the company's planning system consisting of multiple tiers. The system is organizationally structured such that the leader of a meeting is always included in the meeting tier above. The meeting frequency and schedule timeframes of each individual plan are based on the demands of the particular project. A difference to highlight here, when comparing offshore- with construction projects, is that the Strategic planning horizon spans a 5-year horizon across multiple projects.

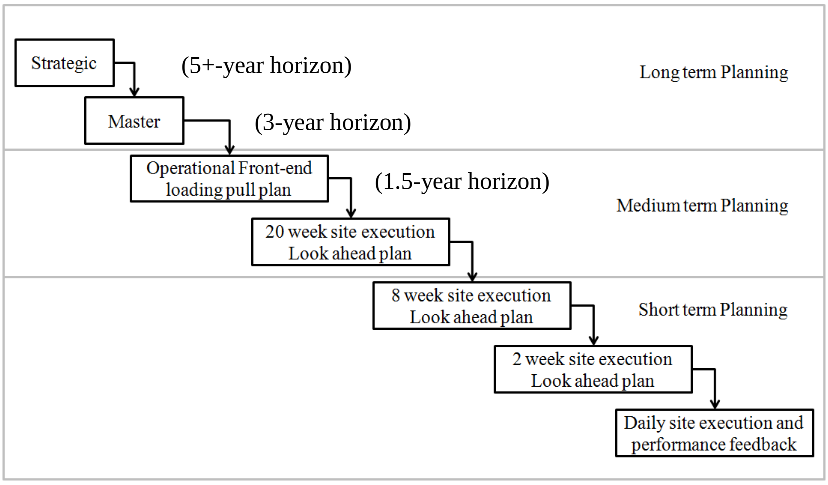


Figure 1 – Example of plan structure

LAST PLANNER® SYSTEM (LPS)

The LPS was developed for construction in the 1990s (Ballard, 2000). The purpose of the planning system was to increase plan reliability, for initial research identified that only about 50% of work planned at the execution level for a given week was completed by the end of the week. Estimators appear to account for this level of plan attainment as well. Thus, if the plan reliability were to increase, then actual production could exceed estimates considerably. As plan reliability increased, the system expanded to improve upstream planning because that was the new bottleneck for production. In all, each process developed as a counter measure to the different problems that emerged while developing the planning system.

The LPS has a hierarchical structure. The philosophy behind the structure is that the further out you plan, the more incorrect the plan will be; and the more detail you plan, the more incorrect the plan will be. Thus it is important to plan at the right level of detail at a given time. At the highest level of the LPS, the master schedule applies to the entire project. A phase schedule is a schedule for a batch of work between two milestones. The lookahead schedule is a schedule that shows work to be made ready; in construction, it typically spans a window of 4 to 6 weeks. At the lowest level, the (weekly) work plan shows what workers have committed to doing the following week.

The first step in the LPS is to plan what **should** be done based on the project objective. This planning goes into the master and phase level planning. The master schedule provides milestones for the project and assesses project feasibility. The phase schedule works backwards from the milestones in order to validate the schedule. This process is called Reverse Phase scheduling, or Pull planning. The purpose of working backwards is to schedule only work that releases work to others. In lean production terms, the work is only being scheduled if a downstream customer requests, or pulls, the work.

The second step in the LPS is to take what **should be** done and screen for what **can** be done. One principle in lean is to not allow defects to move through production systems. Activities are screened for readiness based on the seven flows (Koskela, 1999). The seven flows are: (1) design, (2) components, (3) materials, (4) workers, (5) space, (6) connecting work, (7) external conditions. If the work is not ready or is deemed unlikely to be ready by the scheduled time then it does not move forward on the lookahead schedule. This screening of activities and removal of constraints on the seven flows in the lookahead schedule is known as the Make Ready process.

The third step in the LPS is to commit to work that **will** be done based on the work that **should** and **can be** done. In order to make a reliable commitment, the last planner needs to be able to say no to assignments. A last planner can accept only assignments that meet the following five criteria: (1) definition, (2) size, (3) sequence, (4) soundness, and (5) learning (Ballard and Howell, 2003). Assignments need to be defined and sized correctly so that they can be done within the commitment planning window. At the end of that window they are assessed as either done or not done. There is not a percentage complete assigned at this level due to how percentage metrics can be gamed and, more importantly, the hand-off is key: a follow-on "customer" needs to have all work done in order to proceed with their work. The work is either complete or it is not. In addition, the work needs to be sequenced correctly and the work must be sound (all the prerequisites are complete and the work is ready). Thus, the last planner's assignments meet these five criteria. In the LPS, checking that these criteria are met is known as shielding production (Ballard and Howell, 1998).

The LPS has three metrics: planned percent complete (PPC), tasks anticipated (TA), and tasks made ready (TMR) (Ballard, 1997). PPC is a measure of what percentage of activities planned in the week of execution were completed. TA is a measure of predictability in the planning system and compares common activities between current and past schedules for specific weeks of work (e.g., compare week 3 from last week's schedule to this week's week 2 schedule). TMR measures the ability to remove constraints on future activities and make them ready.

In summation, the focus of the LPS is to identify work that needs to be done, make that work ready, commit only to work that can be done, then perform that work. The final step in the system is to check up on production and identify what was done in order to learn. This learning loop provides the continuous improvement mechanism in the planning system and focuses on improving upon actual plan failures. The three LPS metrics help measure the performance of the system by assessing work performance (PPC), predictability (TA), and the ability to make work ready (TMR). The result of the system is increased throughput, a decrease in accidents on site, and increased planned reliability (Ballard, 2000).

HYPOTHESIS

Four topics in the LPS that may be beneficial to emphasize or adopt in IPL. The topics are (1) work flow metrics in order to enable proactive production control, (2) the concepts of screening and (3) shielding production, and (4) building continuous improvement into the planning process. The hypothesis tested in this research was that activity misses in the schedule would be predominantly caused by reasons the LPS was designed to eliminate.

RESULTS

This research presents data from 30 projects using IPL from a single company. The initial purpose for collecting the data was to identify current practice on the use of IPL in one region in order to develop IPL in a new region. Data was collected from a Primavera 6 web application for the time period of February 2014 to October 2014. The data is comprised of maintenance work and describes why activities were missed at the weekly level. One of 22 disturbance codes was provided every time an activity was not completed (why exactly these 22 remained unclear to the researchers). Table lists these 22 disturbance codes, the disturbance, and the frequency sparkline of the code usage during that time period. In all, the researchers analysed 428 disturbances across the 30 projects with 22 disturbance codes. They analysed unsuccessful activities (disturbances) only and not successfully completed activities. They conducted informal phone interviews for clarification of the data with the head planner of the 30 projects.

Table 1 provides a distribution of the disturbance code usage over the observed time period for all projects. Weather is often cited as a reason for uncertainty and disturbance by offshore workers, nevertheless, only 6% of disturbances cited weather as the cause. In addition, weather affected multiple activities as is evidenced in the sparkline for weather (e.g., data underlying the two spikes in the sparkline on row B4 showed that a storm caused 50% of the disturbances in each of the corresponding weeks). Material related disturbances were recorded in 38% of the disturbances, indicating strongly that work that should be done, should be screened for what can be done. Flight related disturbances were less than 1% of the disturbances and occurred due to inspections being rescheduled. Last, at a minimum 10% of the work being scheduled but not completed was due to planning over the capacity of the offshore workers.

The distribution of disturbances between the projects is positively skewed, for 80% of the projects had less than 5% of the total number of disturbances each. Each project had on average 14.27 disturbances with a standard deviation of 11.77. Some projects had the majority of disturbances, however, data is lacking at this time to gauge whether or not this was simply the result of these projects' sizes.

Table 1 – Disturbance Code Assignment

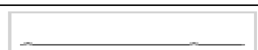
Code	Description	# of Code Usages	Code Usage as a %	Frequency Sparkline (Feb. – Oct. 2014)
A1	No operator available	2	0.47%	
A2	Asst. Operations / Unplanned ESD start-up	5	1.17%	
A3	Unplanned priority 0 or 1 intervention	11	2.57%	
A4	Assistance projects	9	2.10%	
A5	Permit delay	1	0.23%	
A6	Unplanned ESD start-up	0	0.00%	
B1	No flights	2	0.47%	
B2	Delayed flights	2	0.47%	
B3	No material	61	14.25%	
B4	Bad weather	27	6.31%	
C1	Work prep incomplete	45	10.51%	
C2	Wrong material specified	26	6.07%	
C3	No access	22	5.14%	
D1	Wrong material ordered	14	3.27%	
E1	Material not delivered	62	14.49%	
E2	Vendor not present	22	5.14%	
F1	Excessive hours planned	41	9.58%	
F2	Workflow sequence no applied correctly	7	1.64%	
F3	Planning principles not Applied Correctly	28	6.54%	
G1	Scope change during execution	32	7.48%	
G2	Job prep	7	1.64%	
G3	Sick	2	0.47%	

Figure 2 shows disturbances by week. They appear to be cyclical, perhaps due to the nature of planning execution activities 14 days at a time. They also appear to be increasing at a nonlinear rate. A 2-week moving average trend through the data does not confirm this observation however. Weeks 32, 38, and 39 were the worst. Further analysis shows that each of these weeks had different disturbance codes associated with it, with the exception of material related disturbances consistently occurring in all three weeks. In week 32, 43% of the disturbances were related to materials and another 17% were related to vendors not showing. In week 38, 28% of the disturbances were related to excess hours being planned and 28% were also related to materials. In week 39, 40% of the disturbances were related to weather and 31% were related to materials.

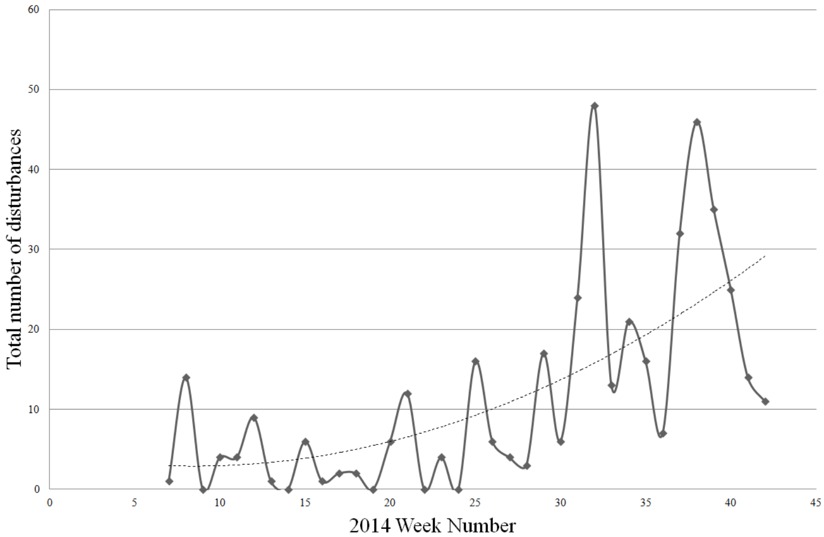


Figure 2 – Disturbances by week for all projects

The head planner was interviewed over the phone to clarify initial findings and understand how data currently was used to promote continuous learning. Every week, each project assessed the previous week in order to identify problems and understand how the plan was executed. Trends in disturbance code usage were not tracked however, so the data presented in this research allowed for new insights into the planning system's performance. Despite not tracking disturbance trend data, planning teams for the projects pursued ways of solving the material related planning disturbances as well as improving work preparations. The head planner was also asked to differentiate between disturbance codes that were outside of the control of planning. Unplanned high priority interventions (occurring from breakdowns or emergencies), sickness, weather, and flights were considered outside of the control of planning, thus they did not have the potential to be reliably screened or shielded for. The remaining 90% of disturbances fell into a category that he agreed the planners have the potential to influence or avoid. Delayed flights may also be prevented by working closer with the flight companies. Last, the increase in disturbances may not be a true increase, but only an increase in the actual reporting for whatever reason (the researchers did not have access to the collection of the data they analysed).

One rule put in place by the head planner had been to not allow work that did not have material ready to be scheduled in the two week execution plan. This rule prevents work of which it is uncertain that it can be done from entering the schedule, so it is an example of shielding. When the head planner started to display the total amount of work hours scheduled without material ready as a metric to the schedulers (Figure 3) that amount rapidly decreased. The first data point shown on September 8th contained nearly 12.5 thousand man hours of work planned without material showing a status ready. As of October 27th, that amount is now showing 573 hours planned.

Data confirming the trend of 12.5 thousand man hours or more planned prior to September 8th was not available to the researchers. The number of materially related disturbances did not decrease as expected, but this could have been caused by an increase in reporting.

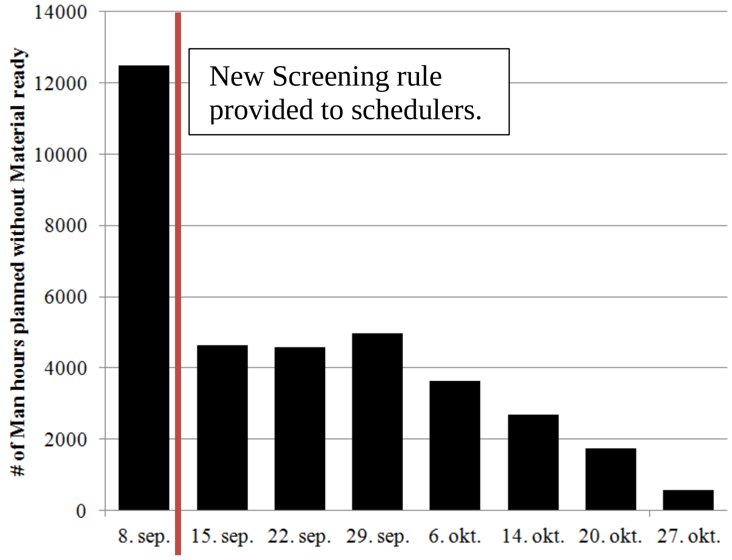


Figure 3 – Number of man hours planned without material showing ready

DISCUSSION

The results from the 30 projects of one IPL implementation at one affiliate indicates that while their IPL system focuses on what should be done, there is a clear disconnect with what can actually be performed at the execution level. Thus, implementing screening and shielding processes would likely increase planning performance of projects using IPL.

The context of the two planning systems is worth discussion. The LPS was developed for construction projects. The master schedule was the highest level, based on the project, and identified if what should be done (i.e., building the project) was feasible. Collaboration between the different parties is between different companies and typically aided through relational contracting (Lichtig, 2006). In general, there is less of a focus on the technological implementation of the system: post-it notes and excel are sufficient to make the system work.

IPL for O&M of offshore platforms is quite different. The network relationships in offshore O&M are not the same as those in construction, thus determining what should go on a plan is much more open for discussion. Collaboration in IPL is primarily within the company between departments. While O&M operations aim to perform proactive preventative maintenance, the inevitable breakdowns of systems and equipment occur. Last, the scale (both in time, 5+ years to daily execution, magnitude, and geographical location of those involved) of planning and execution for offshore operations creates a demand for an IT solution to support all planning.

Continuously improving upon failures and mistakes creates competitive advantage. The LPS incorporates continuous learning by identifying failures in order to perform root cause analysis and eliminate the issues. Furthermore, screening activities and shielding what is scheduled in the execution plan helps identify more problems. While continuous improvement appears in the IPL literature, it is unclear how it is realized in practice. The interview with the head planner revealed that there was no systematic process for continuous improvement in place, though it was still occurring and rules were being implemented to begin to solve problems. While the new rule decreased the total amount of work being scheduled without materials showing ready in the plan, the material related disturbance code usage did not decrease in the past two months.

This data reveals how disturbances codes were assigned to activity misses over a year. If an activity was missed in one week, then appeared in another and missed again, two disturbances were recorded in order to capture every reason and prevent just capturing the last assigned disturbance. However, the cause for a disturbance is subjective because it is up to the senior technician to enter in the cause based on what he or she thinks. The head planner did comment that people would sometimes pick the disturbance code that required the least amount of writing for them to complete. Thus, technicians required some coaching and training to understand the importance of inputting the correct disturbance codes. To highlight one example, a senior technician reported disturbances for material related reasons, but it was later discovered that the correct material was shipped and used to fix a different component. Thus, the real miss was not material related, but occurred due to a change in what was actually executed. One cause for this, as discussed at the 2014 IPL workshop, is that individuals like to fix broken things (Winge, 2014). If the execution plan has an activity for fixing something that does not appear broken, but the technician sees something that is broken, then they may fix the problem that they know exists. Thus, when technicians do not trust that plans actually specify what should be done, they may work on other items not on the plan.

A hypothesis to test in future implementations of IPL is that the adoption of the LPS practices of screening, shielding, continuous learning, and using proactive metrics will improve planning performance. Just one rule that shielded activities on the basis of material readiness decreased planning work hours with unsure or not ready material statuses. Similar screening in earlier stages of planning combined with shielding for other prerequisites could reveal other planning related issues and provide direction for where to improve. Establishing processes for continuous learning based on the data would provide a means to systematically improve.

CONCLUSION

This paper compared the LPS, a system initially developed for project delivery in the construction industry, with IPL, a planning system developed for O&M of offshore oil and gas operations. The literature review identified that IPL emphasizes on collaborating between departments at different scheduling horizons to identify what activities should be performed. The LPS focuses on ensuring that reliable commitments on the execution schedule are made by screening, making work ready, and shielding. Data from 30 projects using IPL practices revealed that over 90% of failures may be linked to not assessing whether the work is ready (screening), not shielding and allowing immature activities to move onto the execution plan, or improper planning. These failures are potentially preventable. A single rule shielded the two week execution plan from activities without ready materials and decreased the amount of planned work without materials from 12,500 man hours to less than 1,000 man hours in under two months. This is significant, first and foremost because all of the work planned into the 2-week schedule needs to be completed (i.e., the schedulers aren't scheduling excess tasks so that the maintenance crews can pull from a large list of tasks and complete what they can: everything on the list should be done). Second, allowing the offshore planners to commit to work that they know can be performed may also surface more production issues and provide additional opportunities to improve planning performance. Third, metrics that assess the ability to screen and make work ready may indicate where production related bottlenecks are occurring. Thus, this research concludes with a hypothesis: incorporating LPS principles of screening, shielding, continuous learning, and using proactive metrics will improve planning performance during maintenance and operations of offshore facilities.

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AN INCLUSIVE PROBABILISTIC BUFFER ALLOCATION METHOD

M. Poshdar[1] , V. A. González[2], Sheila Belayutham[3]

ABSTRACT

The use of buffers in construction presents a tension between theory and practice. From a lean theoretical standpoint, buffers represent waste while they are an elemental part of construction schedules in practice. As a result, a reasonable balance is required to be established between the undesirable waste created by overusing buffers, and high risk of time/cost overruns generated by the lack of buffers. The balanced allocation of buffers includes two main aspects: Determining the size and the location of buffers in the planned schedule. These two factors are significantly affected by the general scheduling policy undertaken to determine the start time of activities. Also, both factors are dependent on the selected set of objectives in the project. Traditional buffer allocation techniques in construction have been informal and often inconsistent in addressing the buffer balancing issues. In this paper, an Inclusive Probabilistic-based Buffer Allocation method (IPBAL) is proposed which applies a mathematically driven strategy to resolve the balanced state in using buffers in construction schedules. It suggests a solution for the multi-objective buffer allocation problem that also accounts for the general scheduling policy. Hence, the method enables shielding the project activities against variability that is one of the steps required to implement lean in construction.

KEYWORDS

Variability, Buffer, Time compression, Scheduling, Network analysis.

INTRODUCTION

The adverse effect of variability is a well-known problem in construction. It generates fluctuations in the flow of work and makes the system performance unstable. Lean construction advocates a strong link between improving project performance and effective variability management. In order to reduce the negative impact of variability and improve planning reliability, Ballard and Howell (1997) suggested to implement lean production in construction in three steps: shielding direct production from variation in the movement of information and materials through the production

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network (workflow); stabilizing the workflow by reducing the flow variation; and improving performance in downstream activities.

Undeniably, even the leanest production systems require a minimum size of buffers as a part of the shielding process (González and Alarcón, 2010). In practice, construction schedule, barely avoid the use of buffers. However, at the same time in Lean, the use of buffers represents waste. In order to resolve the tension between practice and theory, a balanced state is required to be established by allocating buffer in the system (González and Alarcón, 2010). A wide range of production concepts and techniques have been developed, particularly in manufacturing that address buffer allocation issue (Demeulemeester and Herroelen, 2002; González and Alarcón, 2010). However, in most cases, the methods tend to be either extremely simplistic or complex in nature. The simplistic methods ignore crucial details such as the effects of prolonging non-critical chains, and important shape characteristics of the variability model including skewness and kurtosis (Anklesaria and Drezner, 1986; Yang et al., 2008). Simultaneously the extensively complex procedures are time-consuming and impractical. Many of these issues can be addressed using simulation techniques. Nevertheless, the use of simulation in construction can face serious challenges such as knowledge acquisition, model development process, and the black box effect due to which the model is assessed only based on its final outcomes (Abourizk et al., 2011).

This research proposes an Inclusive Probabilistic Buffer Allocation method (IPBAL) that addresses the balanced state in the use of buffers. It contributes to shielding the construction activities that is the first step of the implementing lean construction suggested by Ballard and Howell (1994). The analyses in IPBAL are undertaken using standard construction information such as the expected time and cost of activities. A mathematically-driven strategy has been adopted to process the information. The whole process is streamlined to avoid complex or unrealistic assumptions commonly associated with allocating buffers in construction. This mathematical approach also helps to trace back the results and understand the intermediate outcomes, which can decrease the reported black box effects by simulation users.

RESEARCH BACKGROUND

One of the main characteristics of construction is its uncertain nature. Accordingly, an optimal construction schedule is expected to comply with the uncertain circumstances (Van De Vonder et al., 2006; König, 2011). The extent to which a planned schedule can meet the optimality objectives is determined by using a range of measures. The applied measures can be classified into two general groups:

The deterministic measures which indicate the ability of the planned schedule to achieve certain deterministic objectives such as the *total project duration* (makespan) and *total project cost*.

The stochastic measures which refer to the ability of the planned schedule to absorb distortions. For example the probability of having a *project completion time* equal to or earlier than the planned value (Timely Project Completion Probability-TPCP) and the magnitude of difference between the planned schedule and the actual scenario (schedule stability) (Van De Vonder et al., 2006; Herroelen, 2014).

A good quality schedule should meet a combination of the deterministic and stochastic objectives (Demeulemeester and Herroelen, 2002). Accordingly, any buffer allocation in the schedule should be completed with respect to the intended combination of objectives. A suitable buffer allocation method should consider two important aspects: location and size of buffers (Park and Peña-Mora, 2004). These two factors are significantly affected by the scheduling policy, put toward to deal with the variability effects. The two common scheduling policies in this regard are as follows (Demeulemeester and Herroelen, 2002; Herroelen, 2014):

- Activities start as soon as possible. CCPM advocates using this concept to speed up projects. It permits the schedule to take advantage of the early finish of the predecessors. Thus, the *stability within the schedule* will not be of a primary concern. The concept also is known as *Roadrunner mentality* or *semi-active timetabling*. This policy is denoted by TM1 in the rest of the paper.
- Activities will never start earlier than their planned start time. In contrast to TM1, the *schedule stability* is of high importance in this managerial strategy. The concept is also termed as *railway scheduling approach*. It will be denoted as TM2 in this paper.

As TM1 disregards the schedule stability, shielding the plan at activity level becomes irrelevant. Accordingly, only an integrated source of buffer will be supplied at the end of the planned schedule to protect the project as a whole. On the contrary, in TM2, the individual activities are expected to be adequately buffered and shielded against disruptions.

In this paper, an inclusive method is discussed that determines the optimum allocation of time buffer in a feasible construction schedule. The method takes into account the general scheduling policy while addressing the common deterministic and stochastic objectives adopted in the construction schedule. It determines the trade-off between the objectives that are typically conflicting, and presents the results in an easy to understand style. Hence, IPBAL tends to be simple, easy to follow and reusable that can facilitate its practical site application.

RESEARCH METHOD

The research has been conducted in two major phases:

Conceptual phase: A comprehensive review was undertaken to identify buffering experiences in different fields of science and technology. It explored the common objectives and measures used in construction schedules; the existing methods used to analyse stochastic performance of a construction network; and the available multi-objective analytic approaches.

Development phase: The IPBAL framework was developed to analyse the stochastic performance of activity networks using a consistent mathematical procedure. A combination of objectives is adopted that are quantified in IPBAL using the following deterministic and stochastic measures:

1. Two deterministic measures: expected completion time and total cost of the project.
2. Two stochastic measures: The likelihood of completing the project within the planned time (TPCP); and the difference between the planned values and the *safest probabilistic scenario* that can provide an indication of *schedule stability*. The *safest probabilistic scenario* refers to the shortest expected

scenario that can be met with a probability of 100%. This concept will be discussed further on.

At the final stage, a graphical presentation was created to display the results in a way that assists the interpretation and communication with project personnel.

RESEARCH ASSUMPTIONS

From the conceptual phase, the following assumptions were made in this study:

1. An initial construction schedule (un-buffered baseline for the expected durations) is provided that includes precedence relationships and resource dependencies. It is assumed that the resource dependency is possible to be thoroughly indicated in an *Activity on Arrow* (AoA).
2. The likely variability in activity duration can be reliably modelled using Probability Density Functions (PDFs).
3. Resource availability issue is possible to be converted into the uncertainty of tasks duration.
4. The duration of activities is independent of each other along the network.
5. Total cost of the project comprises of time-dependent direct costs and indirect costs plus the time-independent costs such as cost of materials:
$$TPC = \left[\sum_{i=1}^{n} (DC_i .du_i) + IDC.du_p \right] + cte \qquad (1)$$
TPC is total project cost; DC_i denotes the time-dependent part of direct cost at activity i; du_i is planned duration for activity i; IDC is the time-dependent part of indirect cost of project; du_p is the total duration of project; and cte is the time-independent parts of cost.
6. The quality of the product is one of the important factors in project success and is highly correlated with time and cost (Atkinson, 1999). IPBAL receives the estimations about the duration of activities from project personnel as an input to calculations. It is assumed that the estimates include the minimum time (and accordingly the cost) requirements to ensure an acceptable quality of the final product.

DESIGN OF BUFFERS USING IPBAL

IPBAL includes three consecutive modules. It starts with analyzing the stochastic performance of the project. Hence, IPBAL can evaluate and compare effects of the undertaken scheduling policies and different buffer locating and sizing scenarios on the deterministic and stochastic measures within its next two modules. The results are presented in a comparative graph that enables project decision makers to track interactions between the competitive objectives and find the best compromise between the buffer allocation solutions. Figure 1 presents the stages included within the framework.

MODULE A- NETWORK ANALYSIS (STAGES 1 TO 3)

The establishment of an efficient and accurate method to analyse project network and assess its stochastic performance is a prerequisite to obtaining a proper buffer design that can protect the system. IPBAL adopts a mathematical solution to analyse the expected variability in project performance. The analyses are developed using the information provided by the project personnel at stage 1.

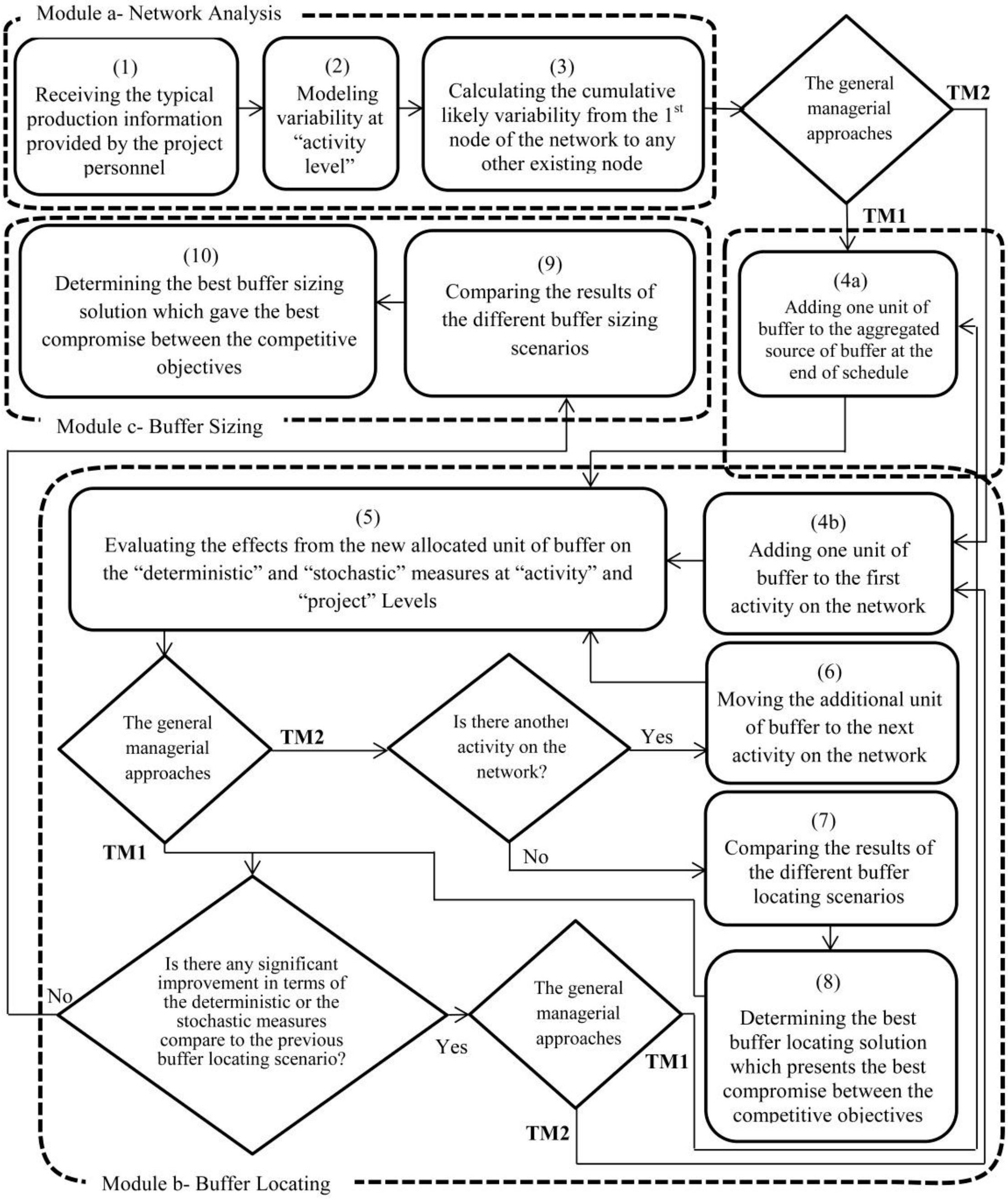

Figure 1. Modules and stages in IPBAL

The information includes the expected time range to complete the activity, and cost-related information such as the direct cost of each activity and the indirect costs of the project. The process of formulating the subjective knowledge from experts is a topic of discussion within Bayesian analysis which is beyond the scope of this paper. IPBAL is flexible in selecting any of the existing elicitation methods. The next two stages process the received data as follows:

In stage 2, the stochastic nature of variability at the activity level is captured using a Probability Density Functions (PDFs). In construction, the use of Beta PDF has been supported by a significant number of researchers. However, further research indicated that Beta PDF faces certain limitations in modelling highly variable processes. Accordingly, the Burr PDF has been suggested as a reliable complement for Beta PDF in such situations (Poshdar et al., 2014).

In stage 3, IPBAL combines the PDFs estimated at activity level based on the proposed method by Dodin (1985). In probability theory, the sum of two PDFs, which represent independent random variables, is calculated using *convolution* (Feller, 2008). However, the development of a distribution that can present the accumulated variability on a network of activities through *exact convolution* in most cases is a very complicated operation (Dodin, 1985; Demeulemeester and Herroelen, 2002). In the *approximate analytic approach* used in IPBAL, the continuous PDfs are discretized and combined in pairs (Dodin, 1985). The overall variability function at project level can progressively be calculated through repeating this algorithm over the network of activities.

To analyse the stochastic performance of the network, IPBAL associates each activity to three random variables:

1. The *time performance* of the individual activity that is characterized by a PDF as per stage 2 of the general framework,
2. The "start time" of the activity, which is governed by the *completion time* of its predecessor(s) on the network,
3. The *completion time* of the activity that is dependent on the two previous variables.

A *cumulative probabilistic index* (CPI) has been introduced to represent the probability functions of the *start time* (CPI_I) and the *completion time* (CPI_C) of activities. The CPI reflects the *accumulated likely variability* through the network, starting from the first node to any intended point on the designed AoA network. The *approximate analytic approach* is progressively developed over the project network. The final CPI_C calculated before the last node of the network represents the overall model of the projects variability.

MODULE B–BUFFER LOCATING PROCESS (STAGES 4A/4B TO 8)

As stated before, if the project follows scheduling policy TM1, the only included buffer will be located at the end of the designed schedule (Stage 4a). For cases in which the project adopts TM2, buffers are allocated to the individual activities. In such cases, IPBAL iteratively adds one unit of buffer to the system and checks the effects of the additional unit to different activities on the project network (stages 4b to 8). The effects are evaluated and compared based on the stated deterministic and stochastic measures of schedule optimality. This approach presents a development over the *Starting Time Criticality* (STC) (Van De Vonder et al., 2006) which uses the same iterative strategy. However, the mathematical approach undertaken to model variability at *Module a* (Figure 1), assists IPBAL to avoid the simplistic assumptions made in STC. It assumes the starting time of any activity is disturbed only by one of its predecessors at a time; and the disturbing predecessor starts at its original planned start time (Van De Vonder et al., 2006). Moreover, STC focuses only on schedule stability objective while IPBAL considers multiple objectives. The iterative procedure in IPBAL continues till no significant gains are made by the newly added unit of buffer in deterministic and stochastic objectives. A multi-layer calculation approach helps to evaluate the achievements of each adopted measures upon adding one unit of buffer to each activity on the network:

Layer 1- Calculating the expected project completion time (the first deterministic measure)

Expected completion time is calculated based on the expected durations provided at stage 1 of the general framework with the additional units of buffer assigned to that activity.

Layer 2- Determining the expected total cost of project (the second deterministic measure)

This layer uses the expected completion times at *activity* and *project* levels calculated in Layer 1, also to the cost-related information provided at stage 1 of the IPBAL framework applied in Eq.(1).

Layer 3- Calculating the likelihood of completing the project within the planned completion time (TPCP) (the first stochastic measure)

Given the expected project completion time calculated in layer 1, together with the project variability model determined at stage 3 of the general framework (the last calculated CPI_C), the likelihood of finishing within the expected completion time can be readily determined.

Layer 4- Calculating the Schedule Stability (the second stochastic measure)

As previously explained, a stability indicator is only of concern if the TM2 scheduling policy is undertaken. IPBAL estimates the schedule stability based on the difference between the planned values and the safest probabilistic scenarios. It represents the maximum probable difference between the planned and actual case. The stated differences can be calculated either in a time-wise scale, cost-wise scale or a combination of both. To bring all the differences to a dimensionless state, IPBAL expresses them in a relative form. Eq.(2) provides a combination of the values:

$$SI = I_{S1}.TSI + I_{S2}.CSI \tag{2}$$

SI is the total stability index that defines the difference between the planned and actual cases; TSI and CSI represent respectively time-wise and cost-wise stability indices; and I_{Si} is the importance factor for each of the defined indices that enable IPBAL to change the share of each TSI or CSI indices in total stability index ($0\% \leq I_{Si} \leq 100\%$).

In IPBAL, the time-wise stability is indicated by the average ratio between the *probability of meeting the planned completion time* and the *probability associated with the safest probabilistic scenario* [Eq.(3)]. The planned completion time for each activity is determined through the calculations in layer 1. The calculated CPI_C models at stage 3 of the general framework provide the probability of meeting the planned time.

Simultaneously, the safest probabilistic scenario is defined as the earliest completion time with its cumulative probability in the proximity of 100% (Figure 2). As for the second assumption of this study, each model contains a point of time after which the associated probability of meeting the plan will stay within the proximity of 100%. Therefore, the calculations of the TSI turns into calculating the average value of the individual stability indices.

$$TSI = \sum_{i=1}^{n} TI_i \Big/ N \tag{3}$$

TI_i is the probability of meeting the designed *completion time* for activity i (Figure 2), and N is the total number of activities on the project network.

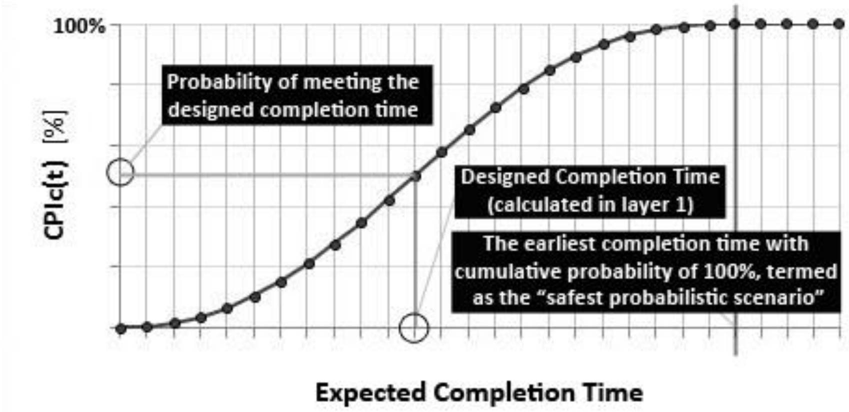

Figure 2. A typical CPI_c function presented in a cumulative format (stage 3)

IPBAL quantifies the cost-wise stability based on the maximum difference between the expected cost with the *total cost of the project* and *maximum probabilistic cost*. It is determined once the buffer locating process reaches stage 8 of the general framework. The *total cost of the project* is indicated in layer 2. The calculated time values for the safest probabilistic scenarios, explained in the previous section will be used in Eq.(1) to calculate the maximum probabilistic cost. The calculations undertaken for each buffer locating scenario are summarized in Eq.(4):

$$CSI = \frac{\left[\sum_{i=1}^{n}(DC_i.du_i) + IDC.du_p\right] + cte}{MaxCost} \qquad (4)$$

DC_i, du_i, IDC, du_p and cte are explained in Eq.(1); and MaxCost denotes the grand maximum of the accumulated costs within each buffer locating scenario.

Different feasible buffer locating scenarios can be quantified and compared by applying the four presented calculation layers. Hence, the buffer locating scenario that gives the best compromise between the adopted objectives can be identified in an iterative approach. This procedure continues until the newly added unit of buffer does not significantly improve any of the objective measures.

MODULE C- BUFFER SIZING PROCESS (STAGES 9 AND 10)

Once the buffer locating process has finished, the suitable size of buffer can be decided. Each additional unit of buffer is associated with a certain level of achievement in meeting the optimality objectives. The values achieved can be plotted on a graph that enables decision makers to track the trade-off between adopted objectives over the different size of buffers visually. Hence, the buffer sizes can be compared to determine a solution that provides the best compromise between the objectives. Figure 3 gives an example of such a comparative graph.

The graph includes four vertical axes where each represents one of the intended deterministic and stochastic objectives. The tick marks on the horizontal axis represent one unit of buffer added during each cycle of buffer locating process. The projection of the buffer size onto the resulted graphs for the adopted objectives determines the score level for each of the objectives. In the end, the final buffer size can be decided based on two major factors: Achieved level in meeting each of the objectives, and Efficiency of the additional units of buffers in terms of differential improvement that can be gained by the objective measures.

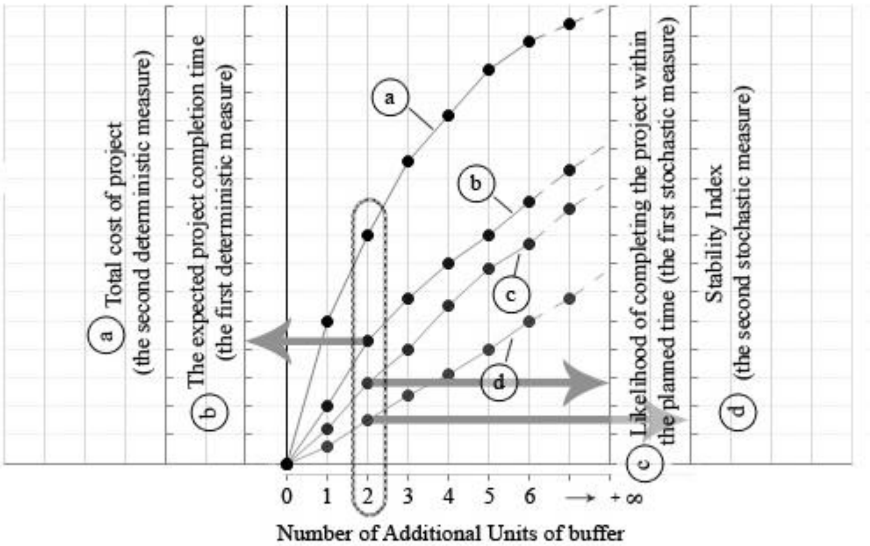

Figure 3 - Graphical presentation of the results

CONCLUSION

A mathematically-driven approach called inclusive probabilistic-based buffer allocation method (IPBAL) is proposed to establish a balance in the use of buffers in construction schedules. The buffer allocation designed provides an optimal solution to meet the common deterministic and stochastic scheduling objectives accounting for two possible policies of scheduling. The proposed method increases the efficiency in designing of the protection of project activities from variation in the workflow. The outcome of IPBAL can be implemented within the existing planning and control methods such as Last Planner System (LPS). It is expected that by enhancing the effectiveness of shielding design in the LPS along with its admitted capability in stabilizing the workflow through reducing the flow variation and improving the performance of the downstream activities, the overall efficiency of the planning and control system will be increased. For this purpose, IPBAL can support a systematic design of the activity protection in both the long-term and the medium-term plan.

IPBAL applies a progressive scheme in the calculation of variability models and buffer allocation that provides engineers with an easy to follow data processing architecture. Also, the presented steps for IPBAL offer a reusable framework that fits conventional practices in construction and can be adapted mostly to any construction work. Such advantages make the proposed framework appealing in practical aspects.

The method presents the analyses results in a comparative graph that offers a significant improvement over current buffering methods that typically rely on a single value solution for buffer allocation purposes. Decision making in IPBAL avoids such restrictions, by providing a range of solutions that can fulfil the deterministic and stochastic objectives in the buffered system. Two ongoing processes of *experimental tests of IPBAL through the records collected from a number of projects*, and *organizing a set of expert interviews* will help to evaluate the accuracy and practicality of the framework.

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SUGGESTIONS TO IMPROVE LEAN CONSTRUCTION PLANNING

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ABSTRACT

The Last Planner System® has been one of the most popular lean construction tools that offers a solution to tackle the problems of production management on construction sites. Since its inception almost 20 years ago, construction companies across the world have implemented Last Planner with reported success. However, even as Last Planner was originally designed to address some shortcomings of the CPM method, a particular shortcoming – namely task continuity was not addressed directly. Also, excepting PPC and Reasons for Non Completion charts, there are no explicit visual tools offered by the Last Planner system. On the other hand, Line of Balance based approaches intrinsically support the consideration of task continuity, and offer a basic visual management approach in schedule representation. With some exceptions, Line of Balance is seen as a special technique applicable only in linear or repetitive work based schedules. The authors suggest that i) there is a need for a robust theory of planning and scheduling and ii) there is a need for a more suitable approach that addresses critical aspects of planning and scheduling function for example by integrating Line of Balance and Last Planner to provide a more robust support for construction scheduling.

KEYWORDS

Lean Construction, Last Planner®, Line of Balance

INTRODUCTION

Planning and scheduling are two of the most important functions from construction management viewpoint. However, the predominantly "Transformation" based Critical Path Method (CPM) that is in widespread use, has been criticised for its shortcomings by researchers over the years (Jaafari, 1984; Koskela et al., 2014). One such shortcoming is the absence of spatial information from tasks, task continuity and the visualisation of it as such. To address this shortcoming, location based scheduling or line of balance method of production planning is often used (Kenley and Seppänen, 2010). To overcome the shortcoming of a predominant "top down" approach and to

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better tackle the variability, the Last Planner® system of production planning was developed (Ballard, 2000), which has emerged as one of the most important lean construction tools since its inception. For many construction organisations embarking on their lean journey, Last Planner is one of the first steps taken. Researchers have also discussed integration of Last Planner with Line of Balance techniques to improve the performance of planning and scheduling in construction (Seppänen, Ballard and Pesonen, 2010).

However, there are still gaps both in practice and in research, in the planning and scheduling techniques and how they are applied in a construction project. In particular as the Last Planner system still takes the traditionally prepared Gantt as the main input (in terms of the Master) schedule, hence the shortcomings of the "T" based system are inherently present up to a certain extent. Moreover, the role of scheduling in general is not formally recognised in the Last Planner system. This makes the connection between the master schedule and low level schedules quite difficult.

This paper attempts to highlight the main gaps in current planning and scheduling methods and argues for the need for a better scheduling theory behind construction. The paper follows the constructive research methodology. The paper begins with selection of problem from practical viewpoint, proceeding to explore the problem area further through literature review. In the following section a connection to theory is made through the proposal of a unified theory of planning and scheduling. Finally, candidate solution requirements are outlined. The next steps of selecting a candidate solution, developing it further and evaluating it in real world are not within the scope of this paper but would follow in subsequent research.

PROBLEMS WITH PLANNING AND SCHEDULING - A VIEW FROM PRACTICE PERSPECTIVE

Based on the practical experience of the authors there are a number of problems with the current approach to scheduling. In a study carried out by Dave, Hämäläinen and Koskela (2015), the authors presented findings on Last Planner implementation based on observations from five companies. The findings highlighted the difficulties in implementing Last Planner, especially the scheduling components by the organisations studied. Table 1 provides a summary of the Last Planner components implemented in each of the five organisations studied.

One critical point raised was that there is not enough recognition for the need for properly developed and updated master schedule i.e. if the current situation on site calls for ad-hoc actions (leading to making-do), they are carried out regardless what the schedule demands. The purpose of the schedule then loses its meaning as a driving/controlling document. The root causes of this problem lie deeper, such as the gap between the long-term plan and medium and short term plans (last planner system), and lack of recognition for an up-to-date master schedule, which results in absence of workable backlog.

Another critical aspect raised by the study was that following the implementation of Last Planner system there was somewhat an ambiguity in planning responsibility, i.e. who should be in charge of maintaining and updating the master schedule and the interface between that and the medium and short term plans.

Table 1 - Last Planner Implementation Summary

LPS Component	Company A	Company B	Company C	Company D	Company E
Phase Scheduling	Not implemented	Not implemented	Not implemented	Not implemented	Implemented
Lookahead Planning	Partial implementation	Implemented	Implemented	Not implemented	Implemented
Weekly Planning	Implemented	Implemented	Implemented	Implemented	Implemented
Collaborative Planning	Partial implementation	Implemented	Not implemented	Implemented	Partially implemented
Analysis and Continuous Improvement	Not Implemented	Implemented	Not Implemented	Not implemented	Implemented

These problems are not necessarily produced onsite or limited to production either. One of the major inputs in developing a detailed production schedule is design information. However, due to cost based procurement methods, or due to lack of recognition of the interface between production and design schedules, the design information is not released in time for the development of a detailed production schedule. A better interface between production and design schedule should lead to the release of design information with a pull from the master schedule.

Traditionally the schedule is an outcome of a site manager's personal experience combined with the characteristics of the project, where task durations are based on experience rather than information such as quantities, consumptions and resources. Locations in the schedule are identified but overall the schedule presentation or execution is not location based. Typically, the focus is on identifying activities / location, not the flow of locations inside and between activities.

Currently, there is too little focus on integrating various trade activities such as MEP, finishes, etc. with the main schedule, which should be planned along with every construction activity. And the sequencing order should be carefully considered, for example whether the pipes should be installed before or after the wall? That should be planned as well in the master scheduling phase and the dependencies included in the schedule.

LITERATURE REVIEW

CURRENT APPROACH TO SCHEDULING IN LEAN

In lean construction, Last Planner® is the most popular production planning method, and as such, there are no explicit lean scheduling methods yet developed. The Last Planner system takes a master plan as the input and the main starting point and tracking tool (from the perspectives of milestones) (Ballard, 2000). While LPS attempts to overcome the problems posed by CPM (a predominantly "T" based approach), by tackling "flow" aspects and by providing a stable planning system, it does not appear to be fully addressing the problems of scheduling.

CPM is still the predominant method, which is a mathematical approach to scheduling that is based on a black box model of input>process>output. In general, this shortcoming results in underperformance of the LPS on construction projects (Dave et al., 2015). Also, the general lack of recognition and integration with a scheduling system in LPS makes it difficult to track projects as it is a scheduling system's role to provide tracking. In LPS, Post it™ notes are typically used as a scheduling aid, typically in short (commitment/weekly) and medium term planning (lookahead). However, it is a manual way of managing information that does not synchronise with other planning and scheduling systems. While the collaborative nature of planning in LPS takes care of the planning functions by addressing the shortcomings of traditional planning and scheduling methods, it does not address the scheduling functions completely. Typically, the integration with master planning, tracking, monitoring and detailed prioritisation, and conflict resolution are not explicitly addressed. Also, while LPS prescribes systematic constraints analysis, the scheduling systems used (such as Post It notes, Excel sheets, etc.) do not directly aid constraint identification as suggested by the LPS.

A study carried out in Brazil (Bortolazza and Formoso, 2006) on 133 projects where Last Planner System (LPS) was implemented highlighted that the main emphasis of the implementation had been on short-term planning. The study pointed out that the effective implementation of the lookahead planning function remained a major problem. In a similar study of over 100 projects in Chile (Alarcón et al., 2005), the authors concluded that only a selected elements of the LPS were effectively deployed, in particular, the make-ready (lookahead planning), workable backlog and corrective actions aspects were not in wide-spread implementation. The study also highlighted the lack of supply chain integration as one of the major problems.

A Swedish study (Friblick, Olsson and Reslow, 2009) in implementation of LPS based on a survey of 270 participants concluded that even though the importance of involving physical workers (i.e. the Last Planners) in the planning process is recognised, it still remains a problem area. Hence, the effectiveness of the collaborative planning aspects remains limited in practice.

It emerges from the study of past literature that one of the most widely implemented aspects of LPS is weekly planning, while lookahead planning, continuous improvement, root cause analysis and collaborative aspects remain a major challenge.

Researchers have attempted to align or evaluate integration of other planning and scheduling systems with Last Planner such as line of balance (Seppänen, Ballard and Pesonen, 2010) and critical chain (Koskela, Stratton and Koskenvesa, 2010) to bridge this gap. However, there is still a need to further develop this discussion and continue to search for a more comprehensive approach to unified planning and scheduling in construction.

In general, the main gaps that emerge from study of literature and practice are:

- Planning and scheduling not taken as a continuous activity and not carried out in an integrated manner.

- Interface between difference schedule resolutions – i.e. top level, medium level and short level schedules is not developed well.
- Task continuity and visualization of flow are missing from the plan and schedule.

DISTINCTION BETWEEN PLANNING AND SCHEDULING

Oberlender (2000) distinguish planning and scheduling activities as “Project planning is the process of identifying all the activities necessary to successfully complete the project. Project scheduling is the process of determining the sequential order of the planned activities, assigning realistic durations to each activity, and determining the start and finish dates for each activity. Thus, project planning is a prerequisite to project scheduling because there is no way to determine the sequence or start and finish dates of activities until they are identified.” Both these terms have been used interchangeably in construction and not much distinction has been made. While, it is not within the scope of this paper to provide a conceptually deeper explanation of these two, the main emphasis in this paper is on scheduling. However, it is implied that a better scheduling method would lead to a better planning output.

SUMMARY

A wide range of literature already exists on the performance of the Last Planner system in various countries. While most studies indicate an overall success story where the Last Planner system improves the overall performance of the project, some also highlight the barriers to implementations and challenges. The majority of the barriers indicated tend to be related to the softer aspects of implementation, such as people and organisational processes, however this in this study the focus is mainly on the functional aspects, i.e. components of the Last Planner system.

NEED FOR A UNIFIED THEORY

Construction planning, and indeed subsequently the whole field of project management, has developed through the emergence of new methods rather than as an outcome of new theoretical insights. Here, the foremost method has been the Critical Path Method (CPM). Also several important alternatives to it, such as the Last Planner System (LPS) and Critical Chain (CC) have their origin in attempts to rectify identified shortcomings of CPM. In contrast, the methods based on line-of-balance (LOB) have had an independent origin.

In prior theoretical work, the underlying theory of traditional project management has been decoded, along with alternative, competing theories (Koskela and Howell, 2002). Also the theories inspiring especially the Last Planner System have been analysed (Koskela and Ballard, 2006).

However, in spite of these advances, the full potential of theory has not been utilized. The theoretical critique against CPM has hardly diminished its use. In practice, there is a trend towards integrating different methods. For example, CPM is customarily used in connection to the Last Planner system, for master planning. In the use of LOB based methods, the need for Last Planner has been felt. These practical developments indicate that there would a need for a unified theory of construction planning.

However, the development of a unified theory is not without challenges. Perhaps the most difficult, and also subtle, difficulty is that our theoretical notions are largely CPM centred, either justifying it or providing alternative solutions. This implies that such parts of aspects of construction planning, on which CPM is silent, will not be visible in our theoretical understanding.

This paper does not aim at developing a unified theory. Rather the aim is more modest: to present some elements which arguably should be included into the unified theory, and which might be usable already as such. We contend that the following elements fall into this category:

- The requirement for continuity (of work, location and time)
- The requirement for visuality of the plan and its preparation.

These two elements represent differing shortcomings of the origin of construction planning, namely CPM. The lack of continuity in CPM is an error even when judged against the logic of the CPM itself, namely, without continuity, tasks will not be optimal. This problem has not been solved in LPS or CC.

In turn, the lack of visuality has become visible through the diffusion of visual management techniques as such, and also through attempts to create production control based on visual management (Brady, 2014).

MAIN FEATURES REQUIRED FROM A SCHEDULING SYSTEM

Table 2 attempts to describe the desired functions of planning and scheduling systems and the roles they need to perform on a construction project (Barták, 1999; Garrido, Salido and Barber, 2000). As noted, a scheduling system should be able to meet several purposes, ranging from sequencing and synchronization to management and monitoring (tracking) of operations, among others functions (Table 1). Despite being useful as a starting point for developing a project schedule, this list of features should not be understood as exhaustive, especially when approached from a lean standpoint. So, a question emerges here: is there any other feature that a scheduling system should contain when approached from a lean perspective? The answer is yes; there are other features that could and should be addressed in a scheduling system when it considers the lean concepts and principles as its theoretical background. These are explored as follow.

Flow. First and foremost, flow has to be properly recognized. In order to do that, aspects such as continuity of tasks and transparency, achieved by the use of highly visual scheduling techniques, should always be taken into consideration. Schedulers should be able to identify visually conflicts resulting from poor allocation of trades on site as well as recognizing the project's critical path so better decisions can be made promptly.

Integration between planning levels. Second, a lean scheduling system should allow for integration between different planning levels. The flow of information from the short-term and medium-term schedules to the long-term plan should be seamless. In other words, planners should be able to know quickly the strategic implications of operational problems as well as there should be a better way to evaluate the repercussions in the master plan of decisions made during the scheduling process. Regarding to the latter, this issue can be more easily verified in complex projects where the high number of workflows and interdependencies might make difficult and laborious the analysis and identification of the best solution in terms of scheduling for the project as a whole.

Table 2 - Features of planning and scheduling (Barták, 1999; Garrido et al., 2000)

Planning	Scheduling
What to make	How best to make it – execution
When to make it – initial sequencing and temporal constraints (at the milestone level)	Detailed sequencing at the task level
How much to make	Synchronisation of activities and resources
Where to make it	Priorities, constraints and conflict
What resources are required	Monitoring execution (tracking) and resequencing/rescheduling

Value Generation. Last, but not least, it is important to mention the need for maximizing value generation through scheduling. This feature has been addressed previously in the paper wrote by Ballard (2000) and (Ballard and Howell, 2003). In order to further develop the Last Planner System of production control, the authors introduced a technique called phase scheduling as a way to perform the scheduling function in construction projects. According to those authors, the purpose of using such a technique is "*to produce a plan for completing a phase of work that maximizes value generation and one that everyone involved understands and supports*". To this end, they recommended the use of pull techniques along with team planning to develop the phase scheduling.

It is worth mentioning that (Ballard and Howell, 2003) acknowledge that the phase scheduling is not the only technique for performing the scheduling function. In this respect and in view of the features aforementioned, the line of balance (LOB) emerges a suitable option as it provides great visibility for the flows of work in a construction site as well as spatial information, therefore enabling managers to assess easily whether tasks have been schedule continuously and whether there are spatial conflicts occurring between different trades. Also, current LOB computerized systems (e.g. Vico System) allow for the identification of the critical path as well as resource allocation, not to mention its ability to speed up the analysis and update of project schedules in an efficient manner. Therefore, it is argued that LOB should be seen as the proper technique for scheduling when lean principles are taken into consideration.

SUGGESTIONS FROM PRACTICE FOR A PLANNING AND SCHEDULING PROCESS

The following has been developed through observations from implementing integrated planning and scheduling in construction projects. It is not meant to be taken as a wholesome solution, but an initial attempt to overcome the difficulties raised above.

- Planning and scheduling should start with these basic steps:
- Creating the location breakdown structure (LBS)

- Identifying the activities and their dependencies (completion order) required for constructing the building (both structural and MEP)
- Dimensioning the activities based on the information available, quantities, consumptions, resources (production factors) and also the know-how of the specific trade contractor. After this the schedule optimization should be carried out.

LBS is one of the main required aspects for the flow. Sometimes it is needed to have different LBS for different phases of the project such as the frame phase and the interior phase as the focus in production is on different things. Activities should be based on locations and should be planned as continuous tasks through the locations to ensure flow is maintained.

The next and as important thing is to identify the correct activities for the project and visualize these activities at the right level. Figure 1 demonstrates one such activity, where screeding and painting are represented as a single activity (as they are in most instances). Figure 2 shows the same activity after it has been expanded and both screeding and painting are displayed as separate activities. It can be seen here that there are clashes between these activities that would lead to problems in execution. However, these problems would not be identified if the activities are not visualized at the correct level.

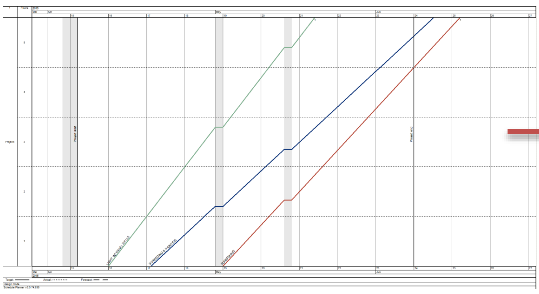

Figure 1 - Summary task of screeding and painting

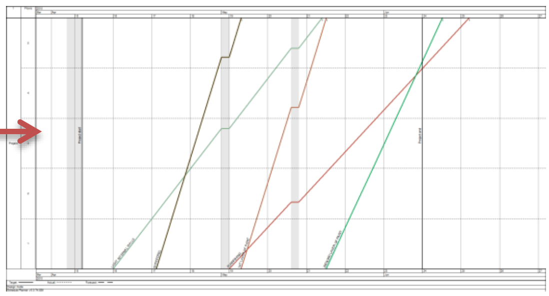

Figure 2 - Screeding and Painting after expanded

In addition to the location based scheduling, and visualizing activities at the correct level, it is also possible to explain each location and timeframe as a self-contained box (albeit with interfaces with other boxes) as shown in Figure 3. In other words, all work related to that activity and location should be completed within the time-location box, if this principle not followed then it may result in delays or clashes with other activities. For example, it is pertinent for the last planners to understand that they have required resources to perform all activities within a time location box once it is expanded.

The duration of an activity is the third important step before the schedule optimization. The duration of a task comes from the equation: quantities x consumption (man-hours / units) divided by the number of resources. The technique is widely used in Finland due to the popularity of the RATU database (see Ratu website, accessed April 6th, 2015), which provides consumption information and standard work methods for construction activities. If one wants to assign the duration based on the experience, the schedule should still be updated with information mentioned in the equation above. Then in case of a production problem, one can find out which part was incorrect: miscalculated quantities, wrong resource assumption or wrong consumption, which would aid continuous learning and help predictability of resource allocation in future.

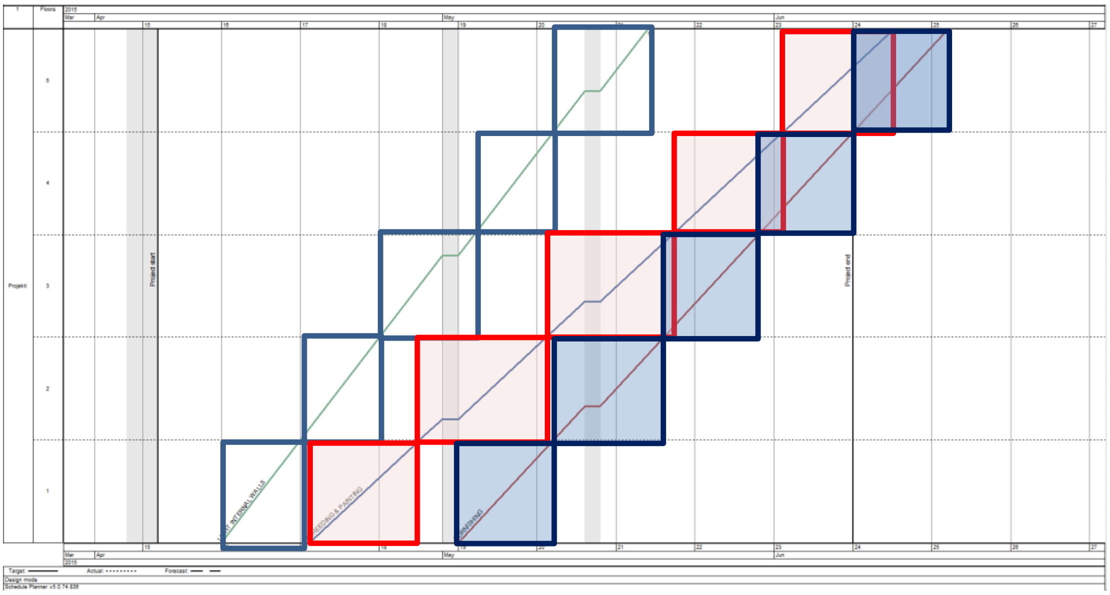

Figure 3 - Activity planning visualisation with location-time boxes

When these steps are done properly one can optimize the schedule, optimize the flow of resources and make sure that the production rates are consistent through every location and communicate the findings with the sub-contractors. It is important to pay attention to resource allocation based on resource consumption, as with Lean and Last Planner while it is possible to steer the project execution towards the schedule and minimize variation, it does not help if the original schedule is inadequate.

In practice, it is observed that quite often these basic things are not done correctly (or at all) and there is a strong need for intervention, which is where Last Planner is useful. But from lean perspective, these aspects should be managed in advance, and the need for intervention should be minimised. The main ingredients of People, process and tools should be sufficient for proper planning and scheduling if they work in a synergistic way.

CONCLUSIONS

The Last Planner system of production management is one of the most popular lean tools being deployed in construction companies across the world. It was originally designed to address practical gaps in the production management process in construction, specifically those left by the Critical Path Method system. However, there are still gaps in the overall planning and scheduling system in construction and role of long range, medium range and short range scheduling system and their interfaces with Last Planner and Location Based Scheduling are not fully understood or explained. This results in gaps in the overall production management system. The lack of an authoritative and in-detail exposition of this system, as well as the missing of an accessible theoretical explanation, figure among the main reasons. While a wider and deeper analysis is warranted, the initial insights discussed provide directions for further amelioration of production control in construction.

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REMOVING HIDDEN WAITING TIME IN CRITICAL PATH SCHEDULES: A LOCATION-BASED APPROACH TO AVOIDING WASTE

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ABSTRACT

Production waste from non-productive activities is a well understood concept in Lean Construction Management.

Waiting-time is also a well understood form of production waste. However, waste arising from the hidden waiting-time inherent in poorly designed CPM schedules has not previously been described. Hidden waiting-time is defined and demonstrated using location-based visualisation methods for construction cycles. A construction cycle refers to a repetitive sequence of work required to erect a structure. Two case studies illustrate how such waiting time can be removed and replaced by production buffers using appropriate levels of location breakdown.

What sort of waste is represented by the time reduction demonstrated in these case studies? The TFV based taxonomy of wastes includes both inefficient waste and waiting time, but combining the two to define hidden waste found in CPM schedules, requires a new category. Cycle waiting time is the waste of not planning the most efficient project structural cycle and therefore not being able to identify hidden wastes based on utilisation of location based structure.

KEYWORDS

Cycle waiting time, waste, work flow, location-based management (LBM).

INTRODUCTION

The purpose of this paper is to add to the theory of construction production waste, from both a practice and a theoretical perspective. Interest in the development of a general theory of lean construction began in the last century. Theory was derived in part, from construction project management practice and in part, through comparative analysis with manufacturing processes. This two pronged approach has provided vigorous debate, growth in the lean construction literature and expansion of the built environment disciplines (Bertelsen, 2004).

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Work flow in construction projects was one of the early lean concepts identified as needing to be distinguished from the concept applied to manufacturing processes (Akinci, Fischer and Zabelle, 1998; Kenley, 2004). Thus, a significant amount of lean construction theory development has been premised on the important distinction between process and operations. In addition, both concepts are derived from practice and theoretical perspectives (Akinci, Fischer and Zabelle, 1998; Howell, Ballard and Hall, 2001). And a growing number of empirical studies have been able to test the theoretical assumptions for improved productivity by implementing lean construction principles in the field (Abdelhamid, Jain and Mrozowski, 2010; Barreto et al., 2014; Kalsaas, 2014).

Empirical studies are possible because a number of methodologies have been developed using lean construction principles. Location-Based Management (Kenley and Seppänen, 2010) and Last Planner (Howell, Ballard and Hall, 2001) are two such methodologies that provide the ways and means to eliminate waste during construction. Thus, identifying and defining 'waste' within the theory of lean construction is important. However, Zhao and Chua (2003) caution that all types of waste affect productivity, but not to the same degree.

Bølviken, Rooke and Koskela (2014) provided a list of specific construction production wastes. The definitions and categorisation are a major step in the development of construction production waste theory. However, as will be argued below, this list can be seen as indicative rather than definitive.

CONCEPTS OF CONSTRUCTION PRODUCTION WASTE

The identification and removal of waste is one of the primary aims of lean methods of construction. A research team working with the Transformation – Flow – Value (TFV) theory developed by Koskela, have focused on creating a taxonomy of wastes of production in construction (Bølviken, Rooke and Koskela, 2014). Table 1 shows both their operational and process wastes linked to work and product flow. The attributes of these two categories indicate 'pauses' in flow (Koskela, Bølviken and Rooke, 2013). The flow perspective highlights internal resources of a construction project, time and location. Activities that pause the flow of work or pauses in product flow can have as a by-product, production waste.

Table 1: Two categories of construction waste identified from a flow perspective

In the Wok Flow	In the Product Flow
Unnecessary movement (of people)	Space not being worked in
Unnecessary work	Materials not being processed
Inefficient work	Unnecessary transportation (of material)
Waiting	

SCHEDULING: A MECHANISM FOR WASTE REDUCTION

There are two types of work flow wastes from the authors' list relevant to this paper (Bølviken, Rooke and Koskela, 2014, pp. 816-817). **Inefficient work** is defined as the waste that results from "doing (necessary things) in an inefficient way" and

waiting is defined as "workers waiting for work to be done". Can **inefficient work** and **waiting** be reduced using an effective construction project schedule?

This paper will attempt to answer the question though analysis in two case studies. *Vico Control, 2009* (Vico Software Inc., 2015) will be used to illustrate CPM schedules in a location-based projection (Flowline). Analysis of alternative schedules will be limited to alternative location breakdown structures (LBS) in accordance with location-based management principles (Kenley and Seppänen, 2010).

CONSTRUCTION CYCLES

A construction cycle refers to a repetitive sequence of work required to erect a structure (Arumugam and Varghese, 2014). Typically this involves both horizontal and vertical elements such as floor plates and columns. These cycles are location dependent, meaning that prior locations must be completed before later locations can commence (Antunes and Gonzalez, 2015).

To demonstrate, Figure 1 illustrates a simple structural cycle of activities: set-out, vertical structure (columns), horizontal structure (slabs); in a location sequence limited to floors.

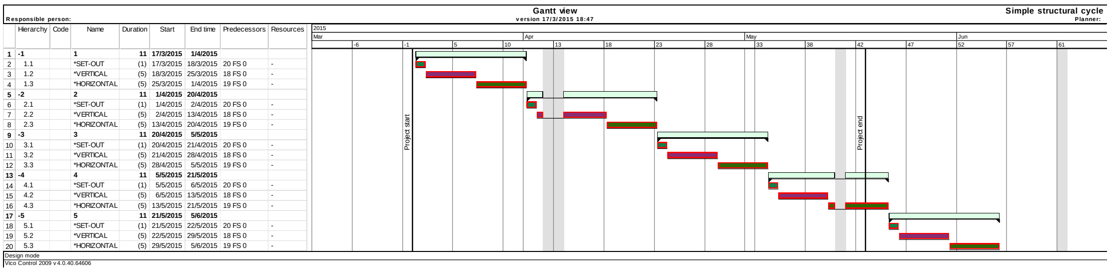

Figure 1: Simple structural cycle with three tasks through five floors

LOCATION-BASED VISUALISATION

As noted in Figure 1, most CPM schedules involve repetitive cycles of work which are location dependent. These cycles typically and necessarily involve a delay (waiting time) as crews commencing the cycle must wait on completion of the cycle below/before starting on a new location. Location-based visualisation can expose this delay by revealing the hidden waste in a construction schedule. Two case studies provide some schedule details of hidden waste within the construction cycles that provides evidence of efficient rather than inefficient work, in the sense of both planning and structural cycle completion.

FIRST CASE STUDY

The first case study is of a 14 level residential apartment building. The project was scheduled using *Primavera P6* and managed using *Microsoft Project*. The structural schedule was cast onto a location-based view using *Vico Control*. Figure 2 shows the structural cycle for the building which was planned and managed on a single pour per floor basis. The final Pour was scheduled for Day 136.

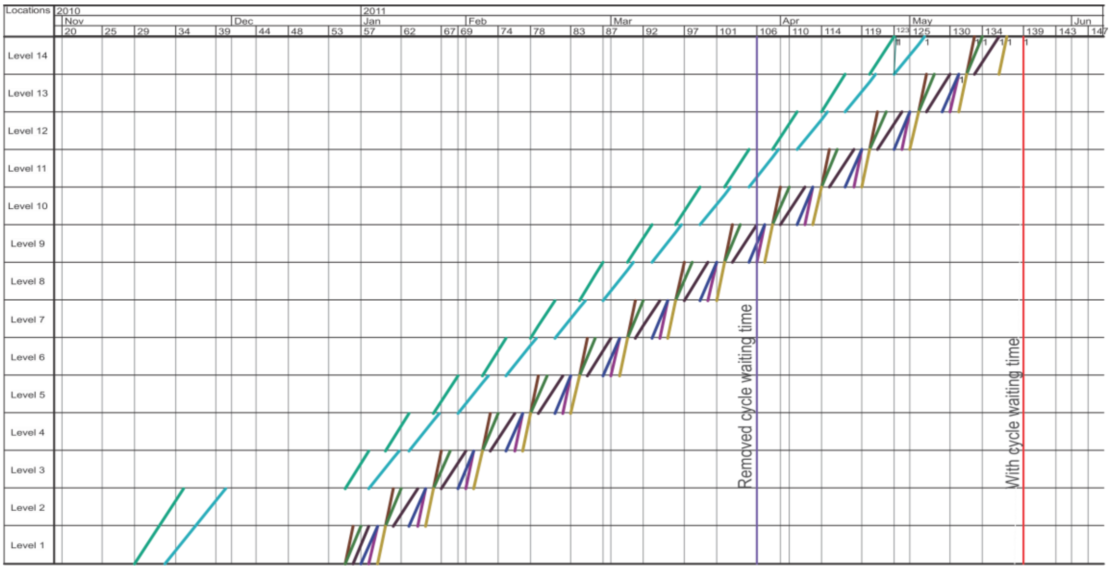

Figure 2: Apartment building planned as one pour per floor. Final Pour on Day 136

If this project is re-planned as a two pour per floor structural cycle, the resultant plan (Figure 3) has a much smoother workflow for individual trades and a total structural duration of 98 Days to the final Pour – a saving of 38 days.

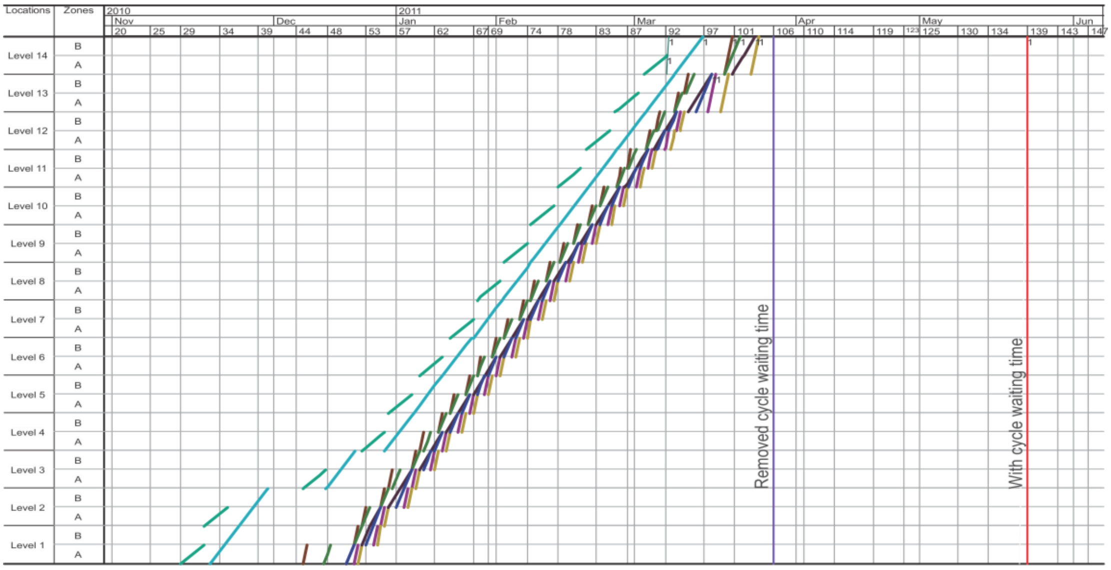

Figure 3: Apartment building planned as two pours per floor. Final Pour on Day 98

The significance of this change is that the simple act of dividing a floor plate into two construction zones can lead to a significant (and cumulative based on the number of repetitions) reduction in overall structural construction time (Akinci, Fischer and Zabelle, 1998).

SECOND CASE STUDY

The second case study is of an education building in which the structure was arranged in three large wings. The project was scheduled and managed using *Microsoft Project*. The structural schedule was cast onto a location-based view using *Vico Control*. Figure 4 shows the structural cycle for the building which was planned and managed as precast construction (columns, beams and slabs) on a single run per wing basis.

The final placement was scheduled for Day 185. The start date for each wing was fixed and could not be reduced.

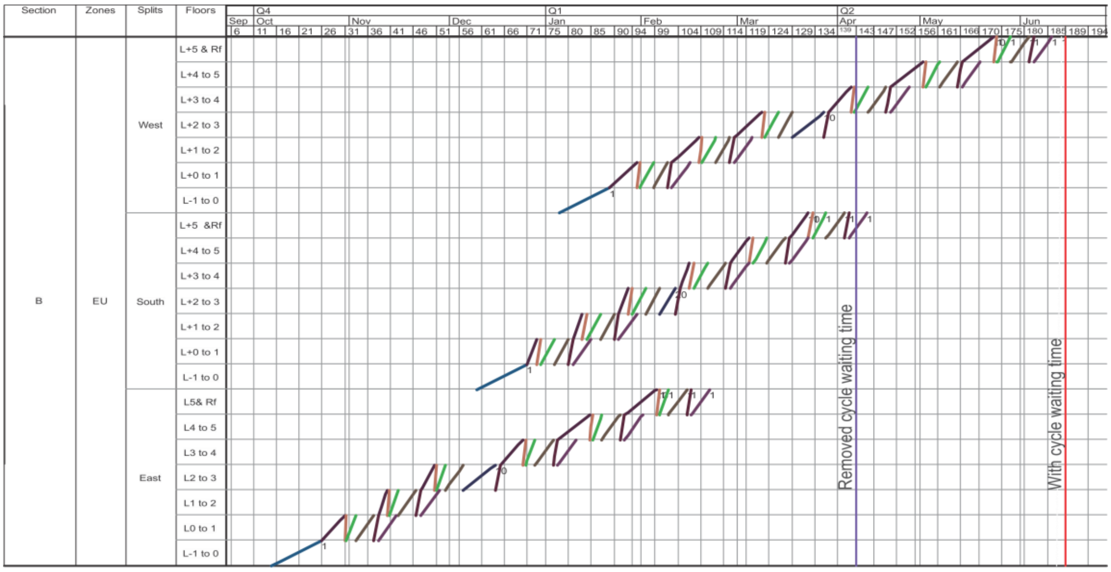

Figure 4: Educational building in three wings with the structural cycle organised as a single run per floor. Total duration 185 days, Wing 3 duration 107 days

Figure 5 shows the same project with each wing divided into two separate work areas. This change did not require additional crews but additional cranage/craneage was required (more cranes for less time = same resource use).

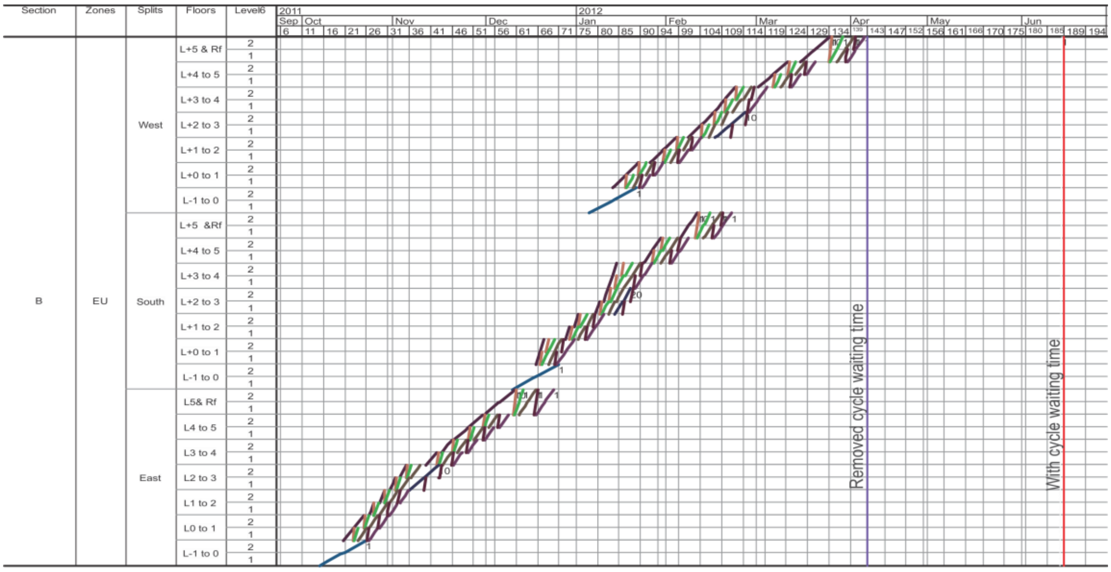

Figure 5: Educational building in three wings with the structural cycle organised as a single run per floor. Total duration 142 days, Wing 3 duration 64 days

With this version the final date for placement was Day 142, a reduction of 43 days. Importantly, as the start dates were fixed, the duration for the final wing reduced from 107 days to 64. This reduction was entirely due to not waiting to complete each work task for the entire wing per floor before commencing the next level.

HIDDEN WAITING TIME

In this special case, **waiting** time does not usually represent waste as defined from the flow perspective: lost time (Bølviken, Rooke and Koskela, 2014). Resources are generally fully utilised doing other work and there is no **inefficiency** involved in the traditional sense. Whether measured on a critical path schedule with logical links and activity durations, or measured by a pull schedule with activities on demand as work becomes available, there need be no deviation from the plan or any appearance of unproductive time (Seppänen, Ballard and Pesonen, 2010).

This improvement is a function of the removal of hidden waiting time in the schedule. The reason it is described as hidden is because traditional CPM planning tools do not reveal the **waiting time**. This simple example appears obvious and most planners would immediately argue that they would plan the project better. The reality is that complex projects planning means lots of activities. However because ignoring the work sequence is far too basic for proper activity modelling, clarity gets lost in the detail of complex critical paths (Kenley, 2005). Because the waste generated by construction cycle repetitive work is hidden, it ceases to be obvious that improvement can be made and **inefficient work** is the perceived outcome**.**

Evidence of hidden waste is demonstrated in the two project case studies. In each case (Figures 2-5) the actual project schedule is compared with an alternative location-based schedule. In the location-based schedule the location breakdown structure is altered to reduce the overall time without requiring any other change in production. And for both examples, waste must have been removed, because total work time was reduced significantly.

DISCUSSION

It is only after location-based analysis that the planner becomes aware of the potential for reducing the overall schedule duration by altering the location-based structure. Therefore, if the location-based analysis is not undertaken (as on most projects) then there is no knowledge of the opportunity to reduce time, but more importantly nor is there a perception of waste. Extending that logic further, it may be seen that a breakdown into three zones instead of two would likely achieve a further (but proportionally less) reduction – and so on until the practical cost of running small construction areas exceeds the value of time reductions (a matter of expert judgement).

Thus, the use of a well-designed schedule means no **inefficiency** is involved in following this location detailed schedule. Certainly if the schedule is met and activities completed on schedule, PPC indicators might be 100% for those activities.

While there is clearly **waiting** involved in this schedule, it might be argued that this is an unavoidable component of structural cycles and therefore not waste.

CYCLE WAITING TIME

What sort of waste is represented by the time reduction demonstrated in these case studies? The two wastes that were identified as relevant to this discussion were: **Inefficient work** and **Waiting**. However, definitions proposed appear to be context specific, rather than types of waste that can be generally applied to project work flow.

So what sort of waste is the identified hidden waste in the two case studies? It could be argued that the Bølviken, Rooke and Koskela (2014) identifiers are accurate but the definitions require revision. On the other hand it makes more sense to propose an additional work flow waste type be added to their list.

The suggestion for the identifier and definition of the type of waste found in this study be: **cycle waiting time** - This is the waste of not planning the most efficient project structural cycle and therefore not being able to identify hidden wastes based on utilisation of location based structure.

CONCLUSION

This paper has made the case for an additional work flow type of waste that can be added to the 2014 construction production waste list (Bølviken, Rooke and Koskela, 2014). **Cycle waiting time** represents a specific type of waste related to structural construction cycle repetitive activities. In most CPM schedules this type of waste is hidden, but it can be exposed through location-based analysis of the structural schedule.

This addition to the theory of wastes is supported by project management practice using a Location-Based Management mythology for lean construction. The two case studies demonstrate clear waste reduction benefits from altering the location breakdown structure for the structural schedule.

Clearly, there are benefits of removing hidden waste from a structural cycle flow regardless of the application of other lean techniques. But, more importantly, without taking into account **cycle waiting time** lean optimisation of project management will be based on a wasteful schedule and will miss the opportunity for improvement.

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COMPLEXITY IN DESIGNING ENERGY EFFICIENT BUILDINGS: TOWARDS UNDERSTANDING DECISION NETWORKS IN DESIGN

Ergo Pikas[1], Lauri Koskela[2], Martin Thalfeldt[3], Bhargav Dave[2], Jarek Kurnitski[2,3]

ABSTRACT

Most important decisions for designing energy efficient buildings are made in the early stages of design. Designing is a complex interdisciplinary task, and energy efficiency requirements are pushing boundaries even further. This study analyzes the level of complexity for energy efficient building design and possible remedies for managing or reducing the complexity. Methodologically, we used the design structure matrix for mapping the current design tasks and hierarchical decomposition of life-cycle analysis for visualizing the interdependency of the design tasks and design disciplines and how changes propagate throughout the system, tasks and disciplines.

We have visualized the interdependency of design tasks and design disciplines and how changes propagate throughout the system. Current design of energy efficiency building is a linear and one-shot approach without iterations planned into the process. Broken management techniques do not help to reduce the complexity.

KEYWORDS

Design structure matrix, design process, process models and modelling, complexity.

INTRODUCTION

Most important decisions are made in the early stages of design, influencing the energy certification levels that can be obtained (Pikas, Thalfeldt, and Kurnitski, 2014). Macleamy's curve is often used for explaining and describing this concept (Eastman, et al., 2011). Designing of civil structures is becoming more complex in terms of technology, technical solutions, organization and its processes. Energy efficiency requirements are pushing these boundaries even further.

Currently, much design energy or resources are spent at the design development and construction documentation stages with the focus on drawing production. Design processes are organized in a sequential and concurrent manner rather than in terms of lean production (Ballard and Koskela, 1998; Ballard, 2000; Morgan and Liker, 2006),

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to reduce the duration of overall design. Many of the problems faced are not caused by designers and engineers, but by prevailing disjointed management (Pikas,et al., 2015) and contracting methods (Howell, Ballard and Tommelein, 2010). Due to budget and schedule constraints, down-stream designers and engineers are not systematically involved in up-stream decision making (Reed, 2009). However, a need for design change amounts into huge rework due to batch and linear nature of design processes. Many of these changes are initiated by the client and/or the architect, influencing other engineering disciplines. Therefore, building design is a complex and multi-objective task, as decisions made by different disciplines influence others.

The purpose of this research is to determine the complexity levels involved in energy efficient building design and possible solutions for managing or reducing the complexity. We visualize how changing architectural solutions influence other engineering disciplines and the energy efficiency and life-cycle costs of the facility. Then, current understanding of design complexity is summarized, and the methods chosen for this research are described, results are presented with possible methodologies discussed for reducing design complexity.

WHAT DOES COMPLEXITY MEAN IN BUILDING DESIGN?

What does a complex system mean? The term 'complex' is often loosely used and its meaning seems to be rather vague. In literature, discussions on complexity are generally divided into three broad categories: product (Suh, 2001; Lee, 2003), process (Eppinger and Browning, 2012) and organization/people (Bertelsen and Emmitt, 2005; Snowden and Boone, 2007). In this article, the main focus is on process complexity, but we also review product and organizational complexity.

PROCESS COMPLEXITY

Bertelsen has argued that construction production and client must be seen as a complex system (Bertelsen, 2003a; Bertelsen, 2003b; Bertelsen and Emmitt, 2005). Taking this discussion further, we need to differentiate between construction and design stages. Pennanen and Koskela (2005) have argued that the design problems are inductive in nature and that there is no single best answer but rather either a good or a bad one; but construction is deductive, i.e., there can be one best answer. Theoretically, in construction simple and ordered systems could be developed with sequential or concurrent tasks (Pennanen and Koskela, 2005). Hence, complexity is rather self-inflicted and caused by organizational structures and people (Tommelein, 2015). Tasks in design are driven by product considerations, which means that in every stage and/or phase, a designer executes tasks that produce product related information required for subsequent tasks – information is flowing (Koskela, Huovila and Leinonen, 2002). What makes design complex is that two or more tasks are coupled (Wynn, 2007) and simultaneously need input from each other.

PRODUCT COMPLEXITY

Lee (2003) has discussed the meaning of complexity in the context of axiomatic (Suh, 2001) and engineering design. He infers that complexity is a property of a system that makes understanding of it difficult. Reed (2009) has compared a building with an "organism" and has stated that like a human body, a building could also be seen as a complex system. These systems have emergent behavior and not all of the causal relationships between systems and systems' elements are understood, which limits the capability of predicting its behavior (Suh, 2001). In engineering design, many statistical correlations are used for doing design and engineering. For example, engineers use statistical averages for building occupation and usage profile or use correlational models for predicting domestic hot water need when calculating energy efficiency for certification.

METHODS

This research is divided into the following steps: we analyze the current design process by using the Design Structure Matrix (DSM); we decompose the life-cycle analysis (Net Present Value, NPV) calculations into its constituent parts. Based on the understanding of the current design processes and the NPV, we have developed a scenario for visualizing how changing architectural solutions influence and propagate throughout the whole building system; and finally, we discuss the possible implications and future research prospects.

DESIGN STRUCTURE MATRIX

In this research, DSM is used for mapping and modelling design tasks related to a specific design stage and discipline. DSM, developed by systems engineers, is used for understanding how engineered structures, processes and organizations are realized through assembly of sub-systems and its elements/components (Steward, 1981; Eppinger and Browning, 2012).

The list of tasks and abbreviations for energy efficient building design (see Appendix 1) has been compiled by observing and interviewing a whole service design office in Estonia. The list of stages, tasks and their dependencies were verified by comparing it to the Estonian national "Building Design" standard (ECS, 2012), legislations (Office, 2012) and guidelines. Subsequently, the Cambridge design modelling application was used for visualizing and optimizing the design process (Wynn, 2007).

HIERARCHICAL DECOMPOSITION OF LIFE-CYCLE ANALYSIS

We used a hierarchical decomposition of the NPV to understand which information and tasks are related, as shown in Figure 1. The NPV itself is a multi-variable value encompassing hierarchically many different decisions made by different disciplines during various stages and with varying level of detail. It is a life-cycle analysis method that enables comparing different design alternatives, i.e., initial energy performance related investment to whole life-cycle energy savings to find a balance between these over the life-cycle of a building (usually 20 years for non-residential and 30 years for residential buildings). The NPV methodology is most widely used by the energy efficiency and sustainability research communities (Kurnitski and Group, 2013).

This helped to understand how the different design functions (dependent variables) and design parameters (independent variables) are related to each other. This decomposition can be compared to zigzagging in the axiomatic design concept - functional breakdown of the product and mapping of design parameters to these functions (Suh, 2001). The designer is describing an artefact in functional terms and maps these to the physical domain (possible physical structure of the artefact).

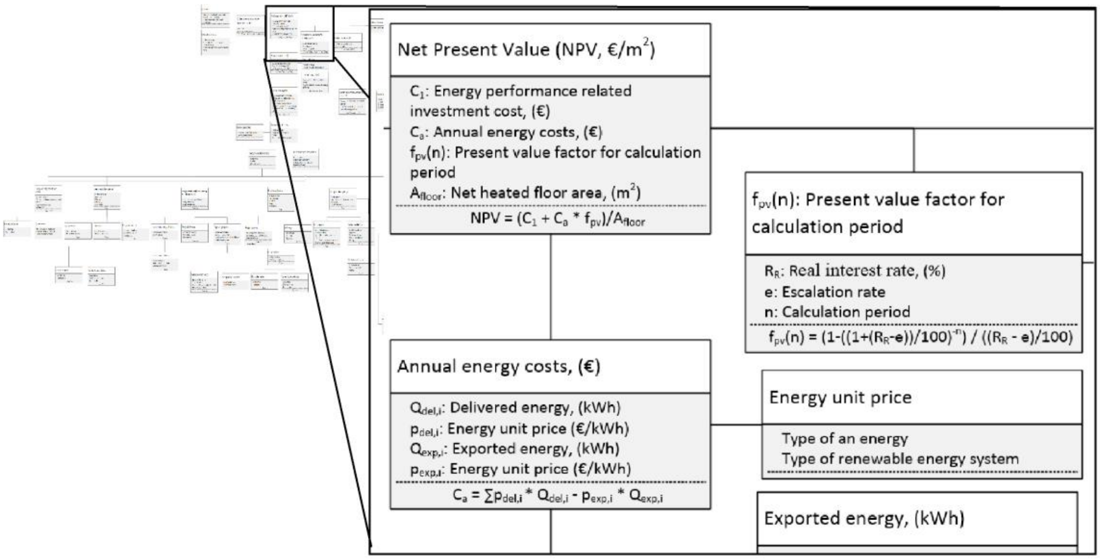

Figure 1. Overall model for the calculation of the life-cycle cost.

DESIGNING ENERGY EFFICIENT BUILDINGS: DSM MODELLING

CURRENT AND OPTIMIZED DESIGN PROCESSES

Figure 2 shows the typical design process for designing the energy efficient buildings. It demonstrates the dominating role of an architect in the early stages of design to close the spatial design or form and shape before solving engineering problems. The DSM diagram also illustrates the batch nature of design; engineers start to work in their batches after the architect has finished. For closing the sequence, the building services engineer enters again to perform the energy efficiency calculations for certifying the energy use level. If the simulation results show that the current design solution meets neither minimum nor client requirements, serious consequences may result. When the client has set only the minimum energy efficiency requirements defined by legislation, typically no problems arise. However, when the client demands higher energy efficiency, for example, a low energy building (B-class), then a typical procedure or sequence of the building services engineer for improving energy efficiency is as follows:

- Identify if more efficient equipment, for instance, heating, ventilation or cooling can help to meet the required efficiency level.
- If not, recommend alternative solutions to the architect, which have minimum influence on the architectural solution (e.g. better windows, more insulation etc.).
- If the energy efficiency level is still not met, then local energy production may provide the solution if they are able to help meet the required efficiency level.
- If not, only in that case reconsider redesigning the architectural shape and form.

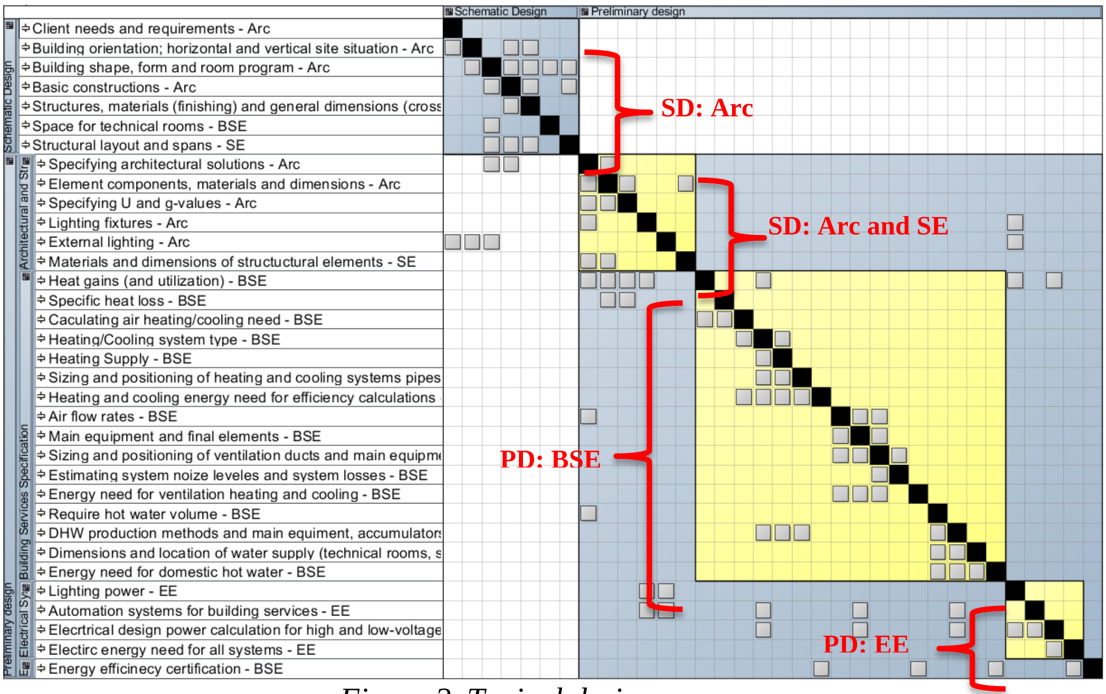

Figure 2. Typical design process.

Therefore, typically the design team prefers to keep the negative feedback loop as short as possible. The longer the negative iteration, the more rework must be done. Secondly, the typical design process presented in the figure above illustrates that the process is already well optimized, as not too many marks are present above the diagonal. As a result of interviews with a project manager, an architect, and structural, building services and electrical engineers, it was found that the current strategy for reducing interdependencies and rework between tasks is standardization and buffering.

Figure 3 shows optimized processes for energy efficient building design.In the next step, we used the DSM partitioning algorithm to reduce or eliminate feedback loops by delaying some of the tasks, as shown in Figure 2 (Eppinger, 1991). The aim was to reduce the complexity by uncoupling or decoupling design tasks. In simple terms, the aim was to reduce the marks above the diagonal by transforming the DSM into a lower triangular form or moving them as close as possible to the diagonal.After applying the algorithm, overall the process remains the same with slight changes, only the building services engineer and the electrical engineer are supposed to work more closely to define automation and nominal system powers, i.e., electric energy needs.

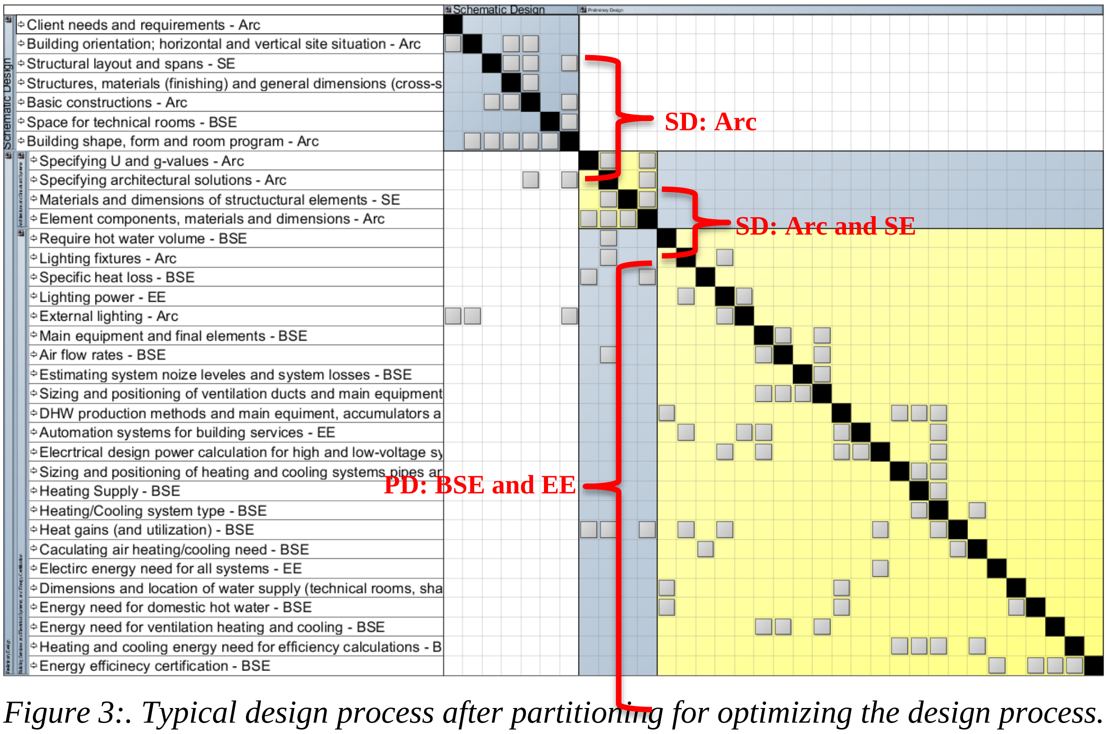

Figure 3:. Typical design process after partitioning for optimizing the design process.

DESIGN SCENARIO AND ITS IMPACT ON THE DESIGNED ARTEFACT

The design scenario is used to determine the relationships between the design parameters, design tasks and disciplines by how building geometry changes during the design development stage influence these aspects.

LATE CHANGE IN BUILDING GEOMETRY

Figure 4 illustrates the impact of changing the building geometry. As can be seen, it changes compactness and the main characteristics of the building (such as areas, design air flow rates, specific heat loss, etc.).This in turn influences the systems, therefore, also energy need and energy delivered, with the production of local renewable energy subtracted. Finally, all this influences construction and annual energy costs, leading to a new NPV of the proposed design solution.

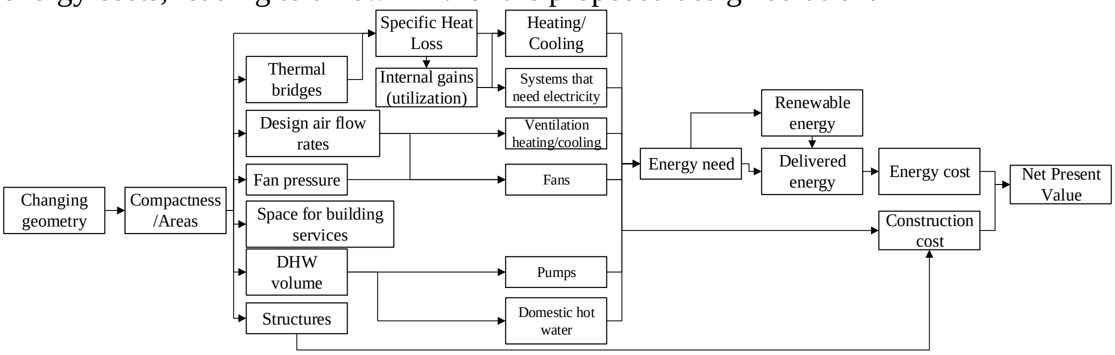

Figure 4. Impact network caused by changing the building geometry.

Table 1 connects design functions and parameters identified in the hierarchical decomposition of the NPV to the design tasks listed in Appendix 1 by using task numbers. Design tasks listed in the Appendix only cover the current design process up to the energy certification calculation. Therefore, rows 9 and 10 in Table 1 have no corresponding tasks because of no clear consideration of construction costs and/or life-cycle costs in a typical design office today. However, according to energy efficiency research community (Kurnitski and Group, 2013) and European Union energy efficiency directives and methodologies, investment costs and life-cycle costs are the major aspects for rationalizing energy efficient building design (Council, 2012). Certainly, these are not the only criteria (Arroyo, Tommelein and Ballard, 2012). Table 1 indicates how late changes in the building geometry influence other design disciplines. Comparing the tasks in Table 1 to the task sequence in Figures 3 and 4, we can see that the changing geometry means a large amount of rework, as everything must be reconsidered.

Table 1. Connecting system design parameters to design tasks and disciplines.

Nr	Design Parameters and Functions	Task Numbers	Discipline	Stage
1	Compactness, Areas	3, 8		
2	Space required for HVAC/MEP systems	6	Architect	Schematic Design
3	Structures	7		
5	Thermal bridges, design air flow rates, fan pressure, specific heat loss and internal gains	14, 15, 21, 26	Building Services Engineer	
6	All systems design: heating, cooling, ventilation heating and cooling, pumps and domestic hot water	All tasks of BSE		Preliminary Design
7	Electricity and automation systems	All tasks of BSE	Electrical Engineer	
8	Energy need, renewable energy, delivered energy, energy cost	34	Building Services Engineer	
9	Construction cost	Not a design task	Contractor/Cost surveyor	-
10	Net present value	Not a design task	Building Services Engineer	-

DISCUSSION

Current broken management methods have not helped to reduce complexity, rather they have increased it. In the literature review and visualization of the existing processes (tasks) and the energy efficiency calculations (design parameters) in Table 1, we showed how the product, processes and organization are interrelated above these three domains. Due to the inductive nature of design, it involves complexity, and it needs to be reduced or managed better. To achieve that, existing and perhaps new methods are needed. We are revisiting here existing solutions, technological and organizational means to reduce or in some instances to manage complexity.

REDUCTION OF PRODUCT COMPLEXITY

Building information modelling (Eastman, et al., 2011) has fundamentally changed the way we represent the functional and physical characteristics of a building in digital form. In historical terms, it has moved from static and illustrative drawings to highly functional and mathematical models that can be used for various kinds of simulations that support design processes and specific tasks, e.g., design coordination through clash detection. Building information modelling can also be used for developing a common language in a project team as it helps to visualize the building in one unified way (3D), understandable to everybody (Alarcon, Mandujano, and Mourgues, 2013).

As in the Toyota (Morgan and Liker, 2006), rapid prototyping (3D printing) could be used for experimenting and studying the different design solutions. This is especially important in the early stages of design (Pennanen and Koskela, 2005). Physical mock-ups/prototypes were largely used in the early years of engineering, especially in the bridge construction (Kranakis, 1997). The 3D printed models can be used for studying their functional characteristics under specified conditions, common to experimental sciences (Godfrey-Smith, 2009).

REDUCTION OF PROCESS AND ORGANIZATION COMPLEXITY

Lean construction (Koskela, 2000), integrative design (Reed, 2009) and/or integrated project delivery (IPD) are examples of reducing process complexity, not only in process terms, but also in terms of organization. These could be viewed as process models that aim to reduce the non-value adding tasks or remove these from the system (Koskela, 2000). Secondly, these approaches break the long communication chains and through colocation, information sharing and communication on design alternatives and solutions is more direct "Knots" can be designed into a process, which contains coupled decisions and tasks (Dave, et al., 2015). This means that design alternatives on different levels of resolutions or decomposition can be internally verified within a project team and validated with the client. Extreme collaboration (Chachere, Kunz and Levitt, 2003) and "Obeya room" (Morgan and Liker, 2006), "Big Room" in lean construction terminology are the methods often used for reducing process and organizational complexity.

CONCLUSIONS

It is evident that most important decisions are made in the early stages of the design process because architect's work influences all the other disciplines. Designing is complex, not only because of complexity within one domain, but because of interdependencies above all three domains: product, process and organization. In this research, we have used the DSM and hierarchical decomposition of the NPV for visualizing the interdependency of design tasks and disciplines and how changes propagate throughout the system. Current design of energy efficient buildings is a linear and one-shot approach without iterations planned into the process. Broken management techniques do not help to reduce the complexity, but lean construction practices together with BIM and other new technologies could be used in managing the design complexity. Regarding buildings as a complex system emphasizes the need for understanding interdependencies in design and the impact of the design changes on the lifecycle costs. New methodologies and technologies discussed above could be used to visualize the impact of design changes to be linked to client's requirements and lifecycle costs.

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COMPARING INVESTMENTS IN SUSTAINABILITY WITH COST REDUCTION FROM WASTE DUE TO LEAN CONSTRUCTION

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ABSTRACT

The Architecture-Engineering-Construction industry shows some resistance in certifying (environmental labels) residential projects and applying lean construction practices due to uncertainty of its related costs and benefits. The most of the researches about green building certification costs are limited to commercial buildings. Few quantitative studies of cost reduction due to lean practices has been published so far. This paper presents a simplified comparative analysis between investments in sustainability and cost reduction due to reduction of materials' waste on a residential project.

The methodology consists of three steps: a documentation study to (1) quantify the extra costs with sustainable features in a LEED residential project and then (2) to determine the reduction of construction waste production by comparing the certified project with a similar building built prior the implementation of lean construction practices. (3) Finally, it was obtained green features and waste reduction costs impacts on the project's final budget.

This study resulted in two indicators, Green Cost and Lean Saving. The Green cost brought an increase of 1.32% on the initial budget due to green building certifications (LEED and INMETRO label) and the Lean Saving represented a 0.19% cost reduction on materials' waste. Thus, the Lean Saving represents 14% of Green Cost.

KEYWORDS

Lean construction, sustainability, waste, green cost, lean saving.

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INTRODUCTION

The Architecture-Engineering-Construction (AEC) industry is responsible for 40% of all waste generated by society (e.g. PNUD, 2012) and represents 8,8% of the Brazilian Gross Domestic Product (GDP) (e.g. ABRAMAT, 2013). To reduce the impacts of the AEC supply chain, the governments and the companies are investing in sustainable initiatives to apply on construction projects.

The effort to improve the process performance led the AEC industry to adapt the principles of Lean Production from the automotive sector to the construction sites. Koskela (1992) brought the concepts and practices of Lean Production to the AEC industry, idealizing the Lean Construction Philosophy.

One of the Lean Production, and thus of the Lean Construction, main goals is related to the total elimination of waste. Ohno (1997) states that the increase in efficiency is directly related to cost reduction: produce only what is necessary with the minimum manpower. An increase of efficiency is obtained when waste tends to zero (e.g. Ohno, 1997). Nevertheless, not many studies quantifying the cost reduction related to the Lean Construction practices have been published yet, mostly due the number of variables involved and the difficulties to identify and quantify it.

In addition to Lean Construction practices, the construction industry has seen the green buildings certifications as a way of reducing the environmental impacts of its activities. For Casado and Fujihara (2009), a green building allows its occupants a more responsible attitude in relation to energy and natural resources through a series of practices that look for efficiency during the building's life cycle.

However, according to the World Green Building Council (2013), there are some green building paradigms to be broken: a green building project and construction is not necessarily more expensive, the added value increases the building's market price, and reduces the operational costs.

THEORETICAL BACKGROUND

The Leadership in Energy and Environmental Design (LEED) certification is one of the main green building certifications, known worldwide. Created in 1998 by the US Green Building Council (USGBC), LEED is in its fourth version and applies to many different building typologies.

LEED certification costs are discussed all over the world. Kats, Braman and James (2010) gathered cost data from 170 green buildings (schools, offices, hospitals, multifamily residential buildings, theatres, universities, etc.) that received LEED or an equivalent certification. They observed that the cost related to the green features vary between 0 and 18%, from which three quarters were concentrated between 0 and 4%. The average of the cost increase was 2%.

Jacomit, Granja and Silva (2009) gathered different studies about LEED certification costs and observed a variation from 0 to 21%. They analysed mostly offices, hospitals, schools and laboratories. Finally, Silva (2013) studied the costs of some sustainable features added to a residential building in Fortaleza, Brazil, resulting in 5.02% cost increase.

RESEARCH METHODS

The methodology for developing this case study was developed by the authors and consisted of four steps:

(1) A literature study to obtain the theoretical basis about lean construction and green building principles and practices.

(2) The selection and characterization of the building's project and the company's historical experience with lean construction and sustainable practices.

(3) Determine the Green Cost by gathering information on costs related to the green building certification processes (certification, design, and material and equipment costs). Determine also the Lean Saving by analysing the reduction of construction waste production after implementing lean practices on the construction site and the reduction on materials losses during the construction work.

(4) Compare both Green Cost and Lean Saving.

CASE STUDY DESCRIPTION

OBJECTIVES

This research paper has the main objective to compare the financial investments to build a multifamily high-rise residential green building, to the cost reduction with waste due the lean constructions practices.

THE CONSTRUCTION COMPANY

Founded in 1975 at Fortaleza, Brazil, the construction company of this case study focuses specifically to Classes A and B. It has more than 700.000m² of constructed area, distributed in various residential projects.

Since 2004, the company has been using many lean tools and practices: *kanbans, andon*, *poka-yokes*, supermarket concepts in the warehouses, transparency, production in small batches, new solutions formatted in the A3 tool, the standardized work tool and many others.

The company's interest for green buildings and environmental certifications started in 2009 to pursue a LEED certification for one of its residential projects. In 2014, the project was LEED Certified.

THE PROJECT

The LEED Certified project analysed in this study is located in a noble neighbourhood in Fortaleza, Brazil. This building has been selected as a case study for being the first residential project LEED Certified in Brazil and due the company's interests in knowing the real costs during its certification process. Its project consists of a single tower with 23 floors and 3 apartments per floor. Table 1 brings the general information about this residential building.

Table 1. General project information

Month / year completion	November/2013
Description	2 parking garages underground, 1 ground floor, 21 standard floors and 1 penthouse floor (duplex)
Units	66 units (3 apartments per floor, 1 with 167,12m² and 2 with 151,14m²
Gross floor area of the building	18.964,32m²
Sustainability matrix grade (Meneses, 2011)	9,70

The building is a LEED Certified project in the category Core & Shell. The certification process began in 2010, and was completed a few months after the completion of the project in 2014. To meet the prerequisites and a minimum of 40 points required to obtain the certification, some sustainable attributes were incorporated into the building's project, such as:

- installation of bike racks in the parking garages;
- rainwater reuse system installation, with VF1 filters;
- roof covered with white high-reflective painting;
- renewable energy use: installation of wind turbine;
- placement of energy efficient lamps and equipment;
- installation of aerator on taps and flow regulator in shower sets, etc.

The building has also the INMETRO Label Level A of energy efficiency for Common Use Areas, which influenced directly the settings of sauna equipment, lamps and lighting fixtures, pumps, elevators and other electrical equipment and appliances. Likewise LEED, to obtain this label it was necessary to meet the prerequisites: the three-phase induction electric motors installed have high performance; and in garages, it was provided a system of mechanical ventilation with automated carbon monoxide (CO) concentration detection. It is important to highlight that the exhaust system for basements is one of the requirements of the commissioning process demanded by LEED.

DEVELOPED ACTIVITIES

This case study occurred into four major stages:

- **Definition of Green Cost:** the Green Cost is the sum of investments made by the construction company directly related to sustainable attributes incorporated into design and administrative costs due to environmental certification LEED for Core & Shell and INMETRO Label. The cost is treated exclusively as percentage.
- **Identify the Green Costs:**
- certification cost: registering and auditing of the project, documents translations and hired consultants;

- design cost: extra costs due design changing to meet the requirements of the certifications;
- costs of materials, equipment and services: investment in equipment, simulations, testing and materials directly related to both certifications requirements. It takes into account the costs of sustainable attributes added to the project exclusively related to the certifications requirements, the green features provided in previous projects were excluded because they are not additional costs. The administration team costs was discarded in this study.
- **Definition of Lean Savings:** lean practices such as long, medium and short term planning, kanban, Andon, poka-yokes, supermarket concepts at the warehouses, transparency, production in small batches, new solutions formatted in A3 tool, the standard work tools and many others are applied in this company for over 10 years. This became a great difficulty in determining the impact of lean practices on the final construction cost. The Figure 1 shows the main stages of Lean Savings defined by the authors. After looking for different indicators, it was decided to compare two similar projects to determine de cost reduction with waste. The LEED certified project was compared to the last project built before the implementation of lean construction practices.

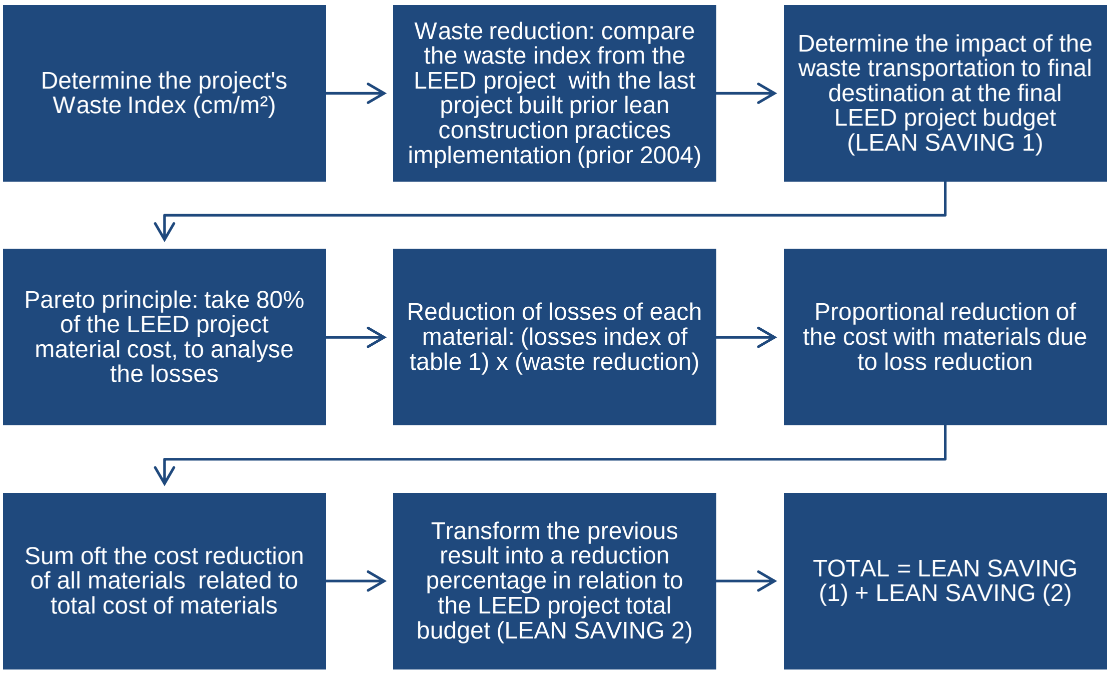

Figure 1. Flux gram of the actions to determine the Lean Saving.

The Waste Index consists of an imaginary layer of construction waste, its height is expressed in centimetres and it is determined by the relation between the total construction waste volume (expressed in m^3) and the building's gross floor area (expressed in m^2). The company follows monthly the Waste Index of each construction site since 2004.

Indicators Analysis: Once determined the Green Cost and Lean Saving parameters, it was performed a comparative analysis between the percentages obtained by checking if there was compensation for investments in sustainable attributes necessary for obtaining environmental certifications.

RESULTS

GREEN COST

Table 2 lists costs added to the project's budget due to sustainable attributes incorporated to meet the requirements for obtaining the LEED certification and meet label requirements of the INMETRO Label for the common areas.

Table 2. Project's Green Costs (%)

Extra costs	%Green cost	%Final budget
LEED pre-certification and certification processes	11.58	0.15
INMETRO Label certification process	4.41	0.06
Total – Certification Costs	*15.99*	*0.21*
Extra design cost – LEED	2.04	0.03
Total – Design Costs	*2.04*	*0.03*
LEED Pre-certification and certification – Exclusively	44.78	0.59
LEED + INMETRO Label – Common costs	26.07	0.34
INMETRO Label – Exclusively	11.49	0.15
Total – Materials, Equipment and Services Costs	*82.34*	*1.08*
Total – Certification + Design + Materials, Equipment and Services Costs		**1.32**

The investments were divided in certification costs, design costs, and costs of materials, equipment and services, for each certification and were analysed as percentage of Green Cost. As mentioned previously, the costs covered in this study do not include sustainable practices implemented in prior projects, as well as costs with employees responsible for certification process.

The results presented in Table 2 show that certification costs accounted for 15.99% of the total invested in sustainability, equivalent to 0.21% of the total building budget, with 11.58% related to LEED certification costs and 4.41% to labelling costs.

Since the decision to get these certifications was taken after the design phase, it was expected that several design changes would be necessary, mostly to meet the US standards referenced by LEED. However, the expectation was not confirmed. It was only necessary to include an exhaustion system on parking garages and adjust the electrical system design to ensure the energy efficiency required by both certifications. These design costs accounted for only 2.04% of Green Cost, or 0.03% of the total cost, and were attributed to project costs of LEED.

Costs related to materials, equipment and purchased services accounted for the largest share of the Green Cost, 81.97% (or 1.08% of the final budget).

Finally, it was analysed the impact of the Green Cost in the initial budget, dated from July 2011. The main costs of material, equipment and services were billed in October 2013; the initial budget was corrected by the Brazilian National Construction Index (INCC).

The investments exclusively related to LEED certification process correspond to an increase of 1.11% on the final cost, while the investments in the INMETRO labelling process correspond to an increase of 0.56%. However, as some cots are common to both certification processes, the combined investment resulted in an addition of 1.32% to the final construction cost (direct and indirect costs).

LEAN SAVING

To determine the Lean Saving, we chose to analyse the production of waste during construction phase in relation to the last project built prior the implementation of lean construction practices on the company's construction sites.

At first, it was gathered the historical data of waste production (in m³) in the construction sites, from 2004 until nowadays (Figure 2). This project has generated 2,072.11m³ of construction waste. Considering the gross floor area is 18,964.32m², its waste index is 10,93cm / m².

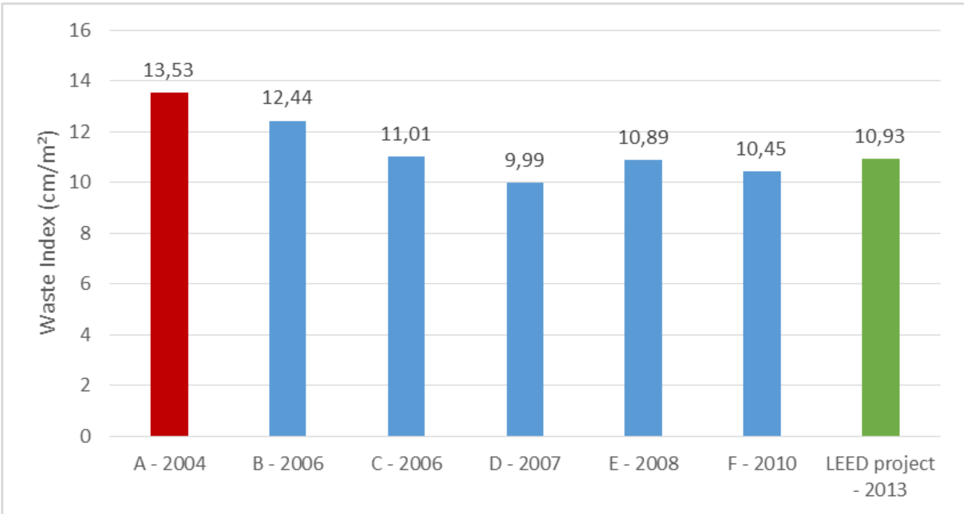

Figure 2. Waste index up to date

Comparing the LEED project with the A – 2004 project, we observe a reduction from 13.53cm/m² to 10,93cm / m², which represents a reduction of 19.24% in construction waste production. It is important to note that the A – 2004 construction site did not have any lean practices and the LEED project construction site comprises almost ten years of learning and continuous improvement in the construction process.

The most recent Waste Index data shows less variation, indicating a trend: the indicator remains between 10,50cm/m² and 11,00cm/m², which may be explained as both consolidation of lean practices and a barrier in relation to construction practices.

The cost of construction waste transport and disposal is about 0.33% of total budget, thus due to the reduction of 19.24% in waste production; there was a saving of 0.06%. In the past 10 years, besides de waste reduction, the company observed a smaller material loss index, resulting in 0.13% saving in cost with materials. Thus, the total Lean Saving of 0.19%, which represents 14.45% of the Green Cost obtained previously.

CONCLUSION

Despite the waste cost reduction and smaller purchase of materials were unrepresentative in relation to the total cost of the project (only 0.19% of the total construction budget), the Lean Saving compensated around 14% of investment in green building certifications.

Moreover, this saving took into account only the reduction of materials losses and a more comprehensive analysis tends to obtain higher percentages. We emphasized that this study did not take into account the costs with employees responsible for managing internal lean practices in the company, as well as cost implementation of lean construction.

It is important to note that the literature on lean construction costs reduction are not numerous, mostly refers to a qualitative analysis of lean practices benefits on a project's final budget. Therefore, the lack of data for comparison gives the results achieved a first impression about the financial impact of lean at the final budget of a residential building.

However, the fact that this project has generated 20% less construction waste (in volume) when compared to a construction site without any concern in process improvement, has a huge value on environmental perspective.

Furthermore, the additional cost to the initial budget due to green building certifications observed on this case study (1.32%), was almost 20% smaller than the average reported by World GBC's survey (Kats, Braman and James, 2010).

CASE STUDY LIMITATIONS AND DIFFICULTIES

We emphasize that this case study has very specific conditions, restricted to the evaluation of a residential building whose builder presents multiple green initiatives and applies lean practices in its construction sites for over a decade. The construction company overcame the initial stage of learning, thus the Lean Philosophy concepts were matured and perfected over the years and were incorporated into its processes.

Note also that the investments made in the implementation of lean practices (training, training, acquisition of equipment and tools) were not accounted, as well as any maintenance costs of these practices, whether in relation to materials and equipment or in respect of employees responsible for managing the lean construction in the company.

It is important to highlight that this paper was also restricted to analysis of the waste reduction related to materials and it was based on theoretical rates of material loss. This limitation is justified because an extensive search in the available literature on the lean construction showed that there are not many records of its impact on the final cost of a construction work. From the difficulties of determining the Lean Saving, we concluded that a detailed study on the costs impacts of lean philosophy involves complex variables whose quantification were impossible in this study.

FURTHER RESEARCH

- Repeat Green Cost analysis provided to other residential or non-residential projects and to other companies with different level of certification and / or other environmental certifications such as the AQUA Process;

- Determine the impact of water and energy savings in operating cost of green buildings and calculate the payback time of the investments required for its construction;
- Conduct a survey of actual rates of material losses on construction sites;
- Determine the costs of implementing the Lean Philosophy in a construction sites due to investment in education and training of employees, in equipment, materials and services;
- Verify the savings provided by lean construction related to labour by reducing effective in the construction site, reducing the number of hours worked and / or productivity gains of the teams.

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INDUSTRIALIZATION, PREFABRICATION, ASSEMBLY AND OPEN BUILDING

Hermes, M. Prefabrication & Modularization as a Part of Lean Construction – Status Quo in Germany. In: *Proc. 23rd Ann. Conf. of the Int'l. Group for Lean Construction*. Perth, Australia, July 29-31, pp. 235-245, available at www.iglc.net

PREFABRICATION & MODULARIZATION AS A PART OF LEAN CONSTRUCTION – STATUS QUO IN GERMANY

Michael Hermes[1]

ABSTRACT

A possible innovative approach to unify construction processes and align it with the industrial mass production, is the integration of industrial prefabrication and modularization in construction.[2] The higher the numbers of identical components, the lower are production costs, which can be a significant competitive advantage. When applying that approach a building gets assembled on site using prefabricated parts and modules are assembled. Especially the use of prefabricated components in the field of technical building equipment still has great potential. For example plumbing units can be delivered and installed on the site already fully equipped. An application in the construction industry, for example, pre-installed ceiling modules (ventilation ducts, cables, pipes, etc.) takes place in Germany but still marginal. Connecting the individual modules is often a problem, but solutions already exist using simple connections. With this innovative production strategy waste during construction process can be reduced. By the associated reduction of individual production steps on site quality can be improved, costs can be reduced and safety for the workers can be increased. The current state of implementing prefabrication and modularization in Germany will be illustrated using examples.

KEYWORDS

Continuous improvement, manufacturing, customization, logistics, standardization.

INTRODUCTION

The leading idea of lean is: "Go to the site of action (Gemba), beware of the real things (Gembutsu), search for waste (Muda) and lead continuous improvement (Kaizen)" (Wilbert, 2009). Dating from the Japanese word "kaizen" literally means "change" or "change for the better" and stands for an ongoing and overall optimization in stages (Schmelzer and Sesselmann, 2008).

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2 The meaning of prefabrication in this paper is the use of stationary prefabricated components. These components have to be only final assembled on site. IGLC Championship defines this as prefabrication and assembly (Court et. al. 2006). The term modularization is used in this paper to describe a systematic partition of a ground plan in equal segments. Modularization should not be confused with the term modularity.

This key principle of the Lean concept applies across all lean disciplines. Kaizen is the basis for Lean Production, Lean Management and Lean Construction. A capital-intensive innovation can cause a sudden break or big changes. In the continuous improvement process, however, is trying to reach a positive change within the company through many small steps. Through a combination of innovation and continuous improvement achieved standards can be secured and new standards can be developed. Thus create competitive benefits of great importance (Kirsch, 2008).

PREFABRICATION AND MODULARIZATION IN LEAN CONSTRUCTION

LITERATURE REVIEW

Continuous improvement can be achieved by various measures. In the construction industry innovative project forms were developed, such as the Last Planner System (LPS) and Lean Project Delivery System (LPDS). The aim of this lean construction tools is to structure the manufacturing processes at the site to ensure a steady flow of information and resources and to avoid waste of resources (Ballard, 2000). This goal is achieved by a collaborative working of all stakeholders at an early stage. Builders, architects, engineers, contractors and suppliers are integrated from the beginning in the planning and can usefully bring in their Know How like that contributing to a positive course of the project at an early stage of the project. The use of simulations helps to optimize production planning processes (Berner, et. al., 2013). As a result, costs are reduced, deadlines are met due to mutual commitments and qualities are planned according to the customer.

However, it is necessary to examine further optimization opportunities to live the Kaizen principle. Especially in the construction industry, there is great potential to improve manufacturing processes and eliminate waste. Material buffer and buffer time can be eliminated by optimizing logistics. An optimized logistics concept contains to a large extent prefabricated components. These can be supplied to and installed on the site just-in-time. It is possible to use the advantages of a stationary production thus reducing working time on construction site. Furthermore the quality and safety at work, is increased by the processing of prefabricated components. Costs can be reduced because many of the same components can be prefabricated in series and not every component needs to be built on its own. The basis for this is that a pattern is used for a building floor plan. It is important that the individual character of each building is not lost. However, it is possible to assign 80% of a building floor plan to an algorithm thus using many of the same components. This modular concept can help to reduce the complexity (Hovestadt, 2014).

Another important point in the context of continuous improvement is the standardization[3] of building products. In the construction industry, there are many manufacturers that produce similar components. However, the components usually have different dimensions and have to be individually adapted to the building.

[3] Standardization: The meaning of the term standardization differs from prefabrication or modularity. International standardization of components (dimensions, connectors etc.) is the basis for a wide use of prefabricated products. An early integration of prefabricated products in the design process requires components standards that fulfill a multivendor-capability.

Standardization, as it exists, for example, in the automotive industry, isn't common yet in the German construction industry. Attempts at standardization have been made, but there was always a contradiction between maximum standardization and flexibility. This restricts creativity why architects often oppose standardized products. But standardization should ensure optimal implementation and contribute to compatibility. Therefore, the focus of standardization is currently at the interfaces between components and not at the individual components per se (Gibb, 1999).

The construction industry is not yet focussing on standardizing systems and products. The focus currently lies on systematically optimizing the organization and processes. Goal must be to effectively utilize the advantages of standard products or components in the early planning process (Aapaoja and Haapasalo, 2014). In this area, there is much to be done to standardize products to appropriate standards and regulations. On this basis, a building can be planned considering the components that will be used and thus ensuring execution-orienting. By defined standards the quality of individual components can be increased (Groenmeyer, 2012).

To use the great advantage of prefabrication in construction projects, a change of thinking in the construction industry is necessary. You may have to move the focus from an individual project execution dealing with unique objects towards a standardized process like in the stationary industry. Therefore, the standardization of products and processes are an essential and maybe even the most important factor to be considered when it comes to optimal prefabrication (Ballard and Arbulu, 2004).

INTEGRATION OF PREFABRICATION/MODULARIZATION IN LAST PLANNER SYSTEM

The Last Planner System is meant as a method of scheduling and production in the planning and in the execution phase. The LPS requires a partnership of the people involved in the project (Last Planner). This can ensure that the required manufacturing process is understood and comprehended by all before starting work. The planning of manufacturing processes in accordance with the LPS forces the supervisor to plan and prepare for the work. It is elementary that they are aware of need of the following trades. Critical points between the individual trades can be addressed in regular meetings during the design phase in order to avoid obstruction on site. Previewing planning guarantees that the necessary information and resources for the implementation of the processes are available on time. Thus, the work can be done according to the joint planning. This reduces waste by faults, reduces costs and gives certainty in meeting deadlines (Gehbauer, 2011).

It is clear that prefabrication is not part of LPS. However the benefits of prefabricated components can be optimally integrated in the LPS. It is particularly useful during the execution phase, to draw on the expertise of the contractors. In this case, not only to the statements regarding the scheduling but also the know-how regarding construction is used systematically. The contractors usually have the best knowledge about the availability of prefabricated products including knowledge about dimensions or other parameters that should be considered in the planning. That fact is the basis for the matching algorithm that needs to be found in order to modularize a building. The objective here is to break down the plan into as many equal areas in which the same prefabricated construction products can be installed.

Applying this modular concept and including mass-produced components, the cost can be reduced by up to 20% (Hovestadt, 2014).

INTEGRATION OF PREFABRICATION / MODULARIZATION IN LEAN PROJECT DELIVERY SYSTEM

The Lean Project Delivery System intends to integrate the executing companies already during planning. The different project phases (design, construction and operation) are looked at integrally in LPDS (Sonntag and Hickethier, 2010). The LPDS is a lean technique that integrates various phases in order to facilitate the design and implementation of construction projects. It is based on close collaboration between the members of the project team. The parties are bound by a code of conduct which does not focus primarily on project success of individuals, but to realize success of the overall process. The LPDS provides a tool to cope with the normal problems occurring on site, such as cost overruns, time delays or poor quality. Furthermore, it contributes to the optimization of the entire design and construction process (Forbes and Ahmed, 2011).

The LPDS integrates the three components of the TVF-theory (transformation, value and flow) and implements them by structuring and control. This contributes to an improvement. The LPDS intends to organize the work on the site so that the three basic objectives can best be implemented:

- Deliver the product,
- Maximize the value,
- Reduce waste.

In contrast to traditional projects, which are divided into different phases (planning, procurement and construction) and are processed separately by a different group of people, the companies involved are already integrated into the decision-making processes during planning implementing LPDS (Ballard, et. al., 2002). Important factors are early procurement decisions. These are required that the suppliers are able to integrate their prefabricated solutions into the early design process. Early selection and early procurement are necessary to do the design around the prefabricated products. This is often called the „Alternative Procurement". All parties are required much earlier in the process (Mawdeslay and Long, 2002).

The LPDS is particularly suitable to take the advantage of prefabricated components to be integrated into the planning process. Thus takes place at an early stage of an execution-oriented planning. If not only executing companies but also substantial suppliers are involved in the project team, who's Know How can be included into the planning. The supplier knows your product best. They can make the planning requirements and know which parameters must be fulfilled that their prefabricated products can be used. Furthermore, suppliers can suggest on how a plan has to be slightly modified (modularized) so that a maximum number of same construction products can be produced. The number of same products lowers production costs and hence the construction costs. This effect is due to the fact that machinery and tools of the production are used more efficiently therefore causing lower unit costs. Furthermore, fewer steps in the production are necessary to setup the machines for new components.

As described, uniform standards for construction hardly exist, it is still necessary to manufacture components individually for each building. However aim is that for each building as many equal parts as possible are used. For this purpose, an individual planning by including executing companies, suppliers and manufacturers is elementary. The LPDS provides an ideal platform for this.

PREFABRICATION AND MODULARIZATION IN GERMANY – A STATUS QUO

BACKGROUND

Certain buildings are built modularized in Germany for many years. Examples of modularized constructions are halls, parking garages or simple hotels and office buildings that are assembled and prepared using special modular system. In this case, there are hardly creative possibilities, as a given raster is compulsory.

Also prefabricated components, which are stationary constructed and installed at the construction site, are also already in use for many years. Especially when it comes to prefabricated houses, prefabricated parts only have to be assembled on site. Prefabricated components are also increasingly used at traditional high building projects. The most common examples are:

- Reinforcement cages,
- Lattice girder plates as semi-finished parts,
- Prefabricated stairs,
- Facade systems,
- Room units systems,
- Wall elements,
- Plumbing units.

Figure 1: Example of prefabricated plumbing cells and stationary production in a hall (Sanika GmbH, Via Primo Maggio 22, 38089 Storo (TN), Italy)

However, this understanding of modularized construction and the examples of prefabrication mentioned above are not further considered. Derived from the example of a plumbing cell, it is intended to demonstrate what opportunities may arise in the prefabrication in the field of technical building equipment. Basis is the classification of an individual, complex building plan into as many equal areas as possible (modularization). Plumbing cells are often prefabricated in the field of technical building equipment. Hence they can be made in a production hall regardless of the weather, dirt and cramped conditions. These bathrooms are turnkey pre-assembled and only have to be put on the construction site with a crane ready to be installed. This usually happens already once the carcass has been erected. During the finishing the plumbing cells must only be connected to the power supply and connected to the pipe network. Ideal fields of application are buildings with high repetitions in terms of room concepts. Explicitly these are hotels, nursing homes, hospitals, residential complexes and correctional facilities.

Especially the technique for connecting the plumbing cells with the pipe network and the electrical wiring has improved significantly over the years. While in the past still complicated soldering took place, one can work with easily and quickly connectable pressing-joints today. This technological progress should be exploited for further pre-assembled modules to take into account in the planning and implementation at the site.

MODULARIZATION OF COMPLEX BUILDING STRUCTURES

As already described, the modularization of a building is essential for the optimal use of prefabricated construction. A complex floor plan can be analysed with the help of computer programs.

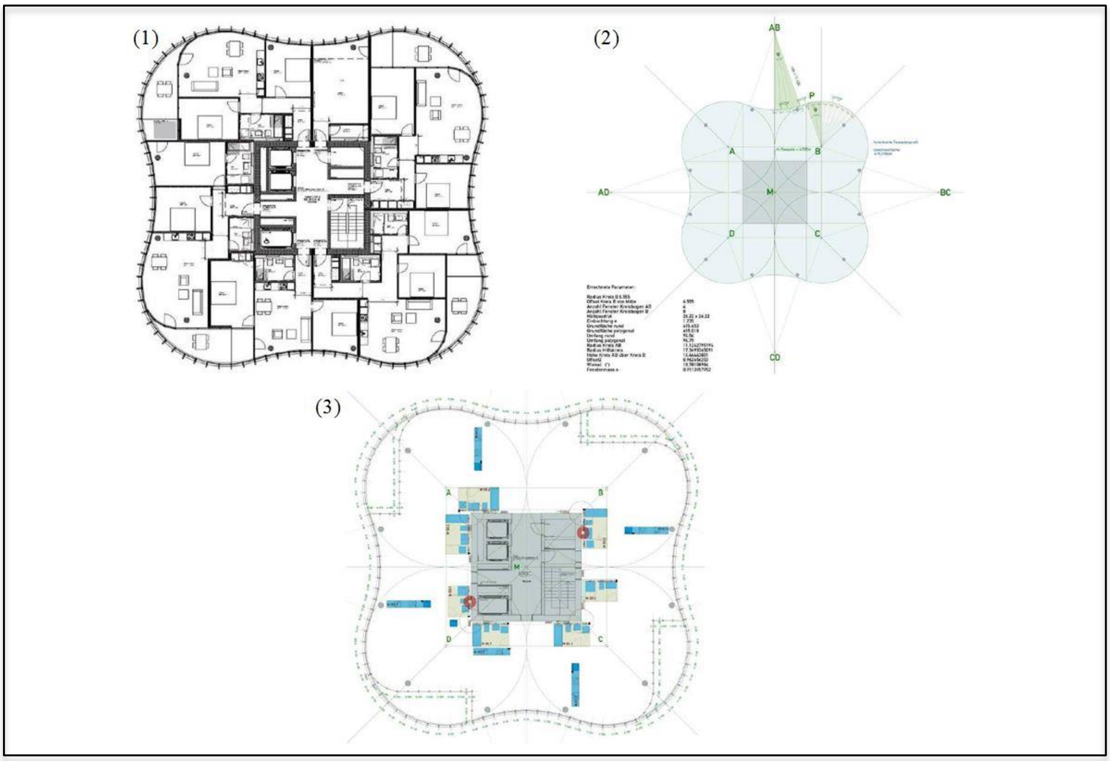

Figure 2: Example for modularization building plan with planning basis (1), project coordinate system (2) and module technology plan (3) (Figure p. 26, 28 and 32 in Hovestadt 2014, Digitales Bauen GmbH, Germany)

Using these data analysis suitable algorithms can be recognized and implemented. The floor plan can be described with a project coordinate system and in this as many equal areas will be presented and created by small changes in the design. This area plans and based on the technology module plans represent the operational area by pre-built series components. Furthermore, the complexity can be reduced in a design and on site-solutions are minimized by this modular construction. A reduced complexity is achieved, less individual solutions are necessary. These details don't have to be individually planned during execution planning and realized on site. This results in more repeats, resulting in higher quality, lower costs and greater adherence to deadlines. Another advantage is that the architectural quality is maintained.

WAYS OF PREFABRICATED CONSTRUCTION PRODUCTS IN TECHNICAL BUILDING EQUIPMENT

The use of prefabricated components is limited in the field of technical building equipment in Germany usually only on Plumbing cells are used. In addition to the time and cost savings, the execution quality can be significantly increased. Just disciplines, which are frequently applied in problems during the design should, as far as possible be industrially prefabricated. These are the disciplines ventilation, heating / plumbing and electrical. Problems occur when the planning does not coincide exactly with reality. Therefore collisions occur often when it comes to the installation of ventilation ducts, pipes and electrical wiring on site. Thus requires improvisation on site. Another critical point is fire protection measures. The most common errors occur here during execution for cable and pipe seals. These are prepared either incorrectly or lose by subsequent line guides their approval. This is precisely this potential of errors that can be avoided by the use of stationary prefabricated components. Goal is to deliver as much as possible prefabricated on the site, so only a final assembly takes place. That means, that the principle of stationary industrial production adapted to the construction industry.

Figure 3: Example for prefabricated ceiling module stationary and installation at construction site (Figure p. 24 und 25 in N. U. 2013, USA)

Reality differs greatly from that vision. However, the technical progress offers many new opportunities. The planning using Building Information Modelling (BIM) lays the foundation for this. Building models can be designed and the structural sequence is also shown. The building model, which is optimized under modularized aspects, sets the parameters for the industrial prefabrication. It will be possible to deliver entire ceiling modules, which are pre-installed with ventilation ducts, pipelines and power lines can already be delivered to the site and they only need to be installed and connected to each other there. This is an exception in Germany. So far the majority still is assembled on the building site in pieces.

The technical requirements are e.g. created by BIM and other programs used for modularization. A stationary production is no problem. One difficulty still has to be eliminated in order to realize prefabrication as mentioned above. That raises the question of the optimal connection technology of these modules. Modern pipes use innovative pressing techniques that replace soldering or welding. With the ventilation ducts the question arises how the ducts can be connected simultaneously while fire protection is guaranteed. Ventilation ducts extend in case of fire and must therefore be provided with fire-resistant joint systems. If possible, this should already been made during prefabrication. Otherwise, it must be done on site and that increases the risk of errors.

There is a big gap to close considering the connection of the electrical wiring. Usually, the cable must be connected to each other by hand individually, which means a lot of effort and thus causes unnecessary costs. Here, it is suitable to develop plug connection systems and further develop existing systems. The target here is to define a common standard that applies across all products and can be used everywhere. The automotive industry has shown us this. As an example of the international ISO 10487 (International Standardizing Organization) standard connector can be called for car radios. Regardless of which radio is installed in the car, it has to be exclusively connected to a plug having to connect properly with each other without any single cable. Comparable standards are important for the construction industry as well and can be optimally implemented especially in the prefabrication of modules. Connectors for construction equipment are already made standardized. It’s obvious that it would be beneficial for the manufactures to develop and define compulsory standards for connectors. A lot of research in the field of connectivity and modularising mechanical and electrical services is already done by the Loughborough University, UK (Court, et. al., 2006). It is recommended to implement these research results in the construction practice, particularly in Germany

Figure 4: Standardized connection according to ISO 10487 (1), Connector construction equipment (ITT Corporation, 100 New Wood Road, Watertown, CT 06795, USA)

CONCLUSION

Modularization and prefabrication can be used alongside many other tools of Lean Construction in order to the objective of continuous improvement. For the application of LPS and LPDS the know-how of manufacturers, suppliers, and construction companies can be shared regarding by available on the market components and products in the planning. Thus, optimal use of prefabricated parts is oriented towards a possible execution. A benchmarking by the Loughborough University, UK shows the effectiveness of the use of prefabricated components (Mawdeslay and Long, 2002). A high degree of serial prefabrication has a number of advantages for a construction project (Pasquire, et al., 2004; Luo, et al., 2005):

- Reduced construction time and saving costs,
- Cost savings as many of the same components that can be produced in series,
- Improved site logistics, as Just-In-Time deliveries may be made attuned to the construction process,
- Reducing the frequency of errors in the execution, being at the construction site for the most part only at the final assembly,
- Improved safety as less work has to be done in harsh conditions at the construction site.

Prefabricated components can be used in the construction industry to a greater extent. There is still a significant need for standardization. To achieve this goal it is necessary that manufacturers develop standards together with construction companies, research institutions and clients. Those standards should be compulsory. Using these standards, the site fabrication can get closer to the already optimized production in the stationary industry. A successful adaptation can increase the productivity in the construction industry (Teichholz, 2013). Construction companies will be enabled to generate adequate return on investments comparable to other business sectors.

Additionally to the research field described in this paper it is important to execute further research. Areas with great potential have been discussed in the IGLC Arena in 2006 by the Loughborough University, UK ("Rapid manufacturing" and "Rapid Prototyping" (Pasquire, et al., 2006)). The steady technical progress in digital building and digital fabrication promotes a wider use of prefabricated components.

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ANALYSIS OF HVAC SUBCONTRACTOR MECHANISMS FOR JIT MATERIALS SUPPLY TO A CONSTRUCTION SITE

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ABSTRACT

Industrialization has been pointed out as a major requirement to improve efficiency, quality, and safety in construction projects. Nonetheless, some of the side effects of industrialization are increasing the complexity of construction by including new technologies, engaging different subcontractors; increasing interdependencies between trades; and so forth. The aim of this paper is to develop a planning procedure for facilitating the integration between off-site fabrication and on-site installation, for achieving a just-in-time delivery, based on an action research study conducted with an HVAC subcontractor. It is part of a wider research project, aiming to develop a planning and control model for engineer-to-order (ETO) prefabricated building systems. The procedure developed in this research helped the team to review the schedule proposed by the GC in terms of constructability, get team consensus regarding installation sequence, improve communication between contractor and fabricators, support fabricators in defining fabrication rhythms and mix of production; and helped the project team solving logistic challenges. The main challenge faced in this research was related uncertainty and unforeseen changes to the developed plans. As a result, we also explored a way of tying fabrication plans to critical activities in the job site to facilitate matching fabrication rate with site demand.

KEYWORDS

ETO building systems, Feedback mechanisms, Production planning and control systems, Just-in-time, pull-production.

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INTRODUCTION

The growing use of industrialized components in construction has contributed to make the construction industry more efficient, increasing the reliability of construction projects in terms of delivery time and quality, and reduced the risk exposure in construction sites. It is a movement of mirroring the environment of the manufacturing process. Lessing (2006) describes the idea of industrialized building as a complex concept including technical and organizational aspects as well as the supply chain and information-related issues. This type of conceptualization reveals the complexity inherited in the use of industrialized techniques.

An important competitive advantage in this context is the focus on engineered-to-order (ETO) production systems, which means that the customer order is a unique project and the outcome is the final assembled product (Bertrand and Muntslag, 1993). In this study, ETO prefabricated building system refers to one specific building sub-system, namely the Heating, Ventilation, and Air Conditioning (HVAC) system, delivered by a single company.

In an ETO production system, the products have not been specified when the customer places an order and the main criteria for deciding to choose a company is the price and lead-time for production (Bertrand and Muntslag, 1993). For this reason, the interface between the design, fabrication, and site installation of these components have to be analysed in an integrated manner, in order to check whether the company is able to deliver the product keeping the price and the delivery time previous agreed.

This research addresses the challenges of managing ETO components in a complex and fast construction project, from a subcontractor perspective. This study was possible thanks to a partnership between the Project Production Systems Laboratory (P2SL) at UC Berkeley, and Superior Air Handling, a mechanical contractor specialized in the market niche of complex construction projects. Two different papers report the findings of this investigation. This first aims to develop a planning procedure for facilitating the integration between off-site fabrication and on-site installation, in order to make the subcontractor able to make just-in-time deliveries in the site. The second paper (Tillmann et al., 2015) discusses the challenges faced while transitioning from design to production, and the role of different mechanisms, e.g. BIM and lean techniques to support that transition.

RESEARCH METHOD

The research approach can be framed as a design science research (March and Smith, 1995), since a planning procedure was developed to enhance the communication between the subcontractor superintendents, the different fabricators, and with the general contractor of the project. The study was held from September 2014 until February 2015, as part of the collaboration between the P2SL and Superior Air Handling. The main sources of evidence were (1) document analysis, mainly schedules and productivity data from previous projects; (2) interviews with the superintendents, project managers and vice-president of the company, and with the fabricators; (3) direct observation on internal meetings for weekly work-plan and for internal progress status, (4) visit to different fabrication facilities.

The authors of this paper worked collaboratively in the HVAC contractor project office, understanding the demands from the general contractor and the capacity of the different fabricators. The outcomes of this investigation have been discussed with the team members who had an important role in improving the procedure shown in this paper. During the period of the research, two workshops were carried out in order to share the knowledge developed.

ABOUT THE PROJECT

The project investigated has almost 300.000 sq meters of building area, located in a construction site of almost 780.000 sq meters, and its cost is of around 5 billion dollars. The project used mainly industrialized technologies, to improve efficiency and deal with a fast pace schedule. There was also little space in the job site for contractors to keep any inventory, which contributed for the decision to carry out most of the activities off-site.

In the beginning of the project, the general contractor developed the first schedule for the whole project. The general contractor makes a differentiation of the role of some subcontractors. Some subcontractors are responsible for critical path activities, which means that a delay on their activities could pose a threat to delivering the project in the promised date. This was the case, for instance, of subcontractors responsible for the concrete and the steel structure of the building. These subcontractors had an important role in the production planning and control system of the project as their production frequently dictates the pace of the other subcontractors. In this paper, we call them "**critical**" subcontractors, as their work compound the critical path of the project.

Another important characteristics of a subcontractor work identified in this research was what we called "**window of opportunity**". When analysing the schedule, we observed that the work of MEP subcontractors were allocated between critical activities that cannot be delayed. MEP subcontractors tend to plan their work based on how much time they have to install the equipment after the area is made available for them and before the next activity blocks their access to the area, e.g. time after concrete slab is available and before roof structure is installed, which would make it difficult to bring large equipment. Those windows of opportunity were the main source for the HVAC subcontractor to plan their work and establish the production strategy. This window could fluctuate in time, and sometimes be compressed or extended, as shown in the different versions of the GC schedule in Figure 1. Here, the windows refers to the work in the penthouse of the building. The release for starting the work was delayed two months, and the time available was prolonged. The need for working with a flexible plan within this window of opportunity determined the implementation process, as described in the next section.

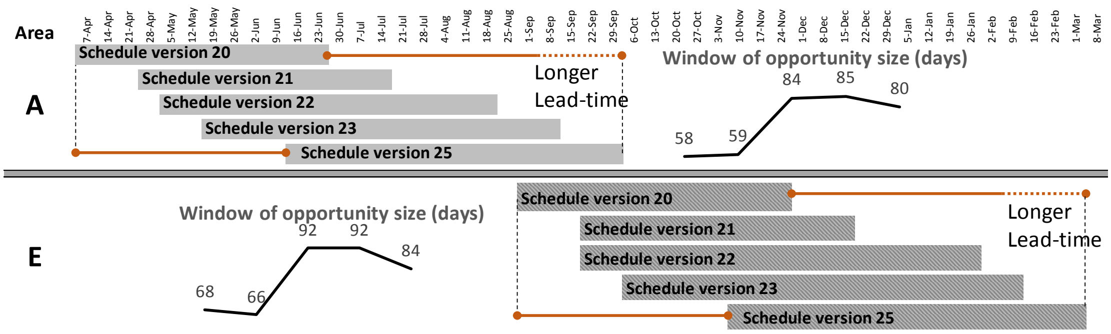

Figure 1: Changes in the window of opportunity for a given activity

RESULTS

The desire to achieve just-in-time delivery of mechanical components was the main driver for developing and implementing a planning process that integrates site installation and fabrication. Three critical activities were analysed: (a) installation and fabrication of risers; (b) installation and fabrication of air-handling units (AHUs), and (c) logistics and installation of different equipment in the penthouse.

RISERS

A riser consists of a vertical sheet metal duct connecting the ductwork of each floor to a fan and a plenum unit in the penthouse. The installation of risers is critical because it comes in one single 24-meters-heigh piece, which has to be hoisted, rotated and installed at once, in half of a day. There are 80 risers throughout the project, the crane for the mechanical contractor installation was shared with an electrical team, who had to install a riser in the same shaft. Because of this interrupted flow the rhythm of installation was on average of one riser each 1,5 (one and a half) days. The analysis consisted in four steps:

a) Creating an installation plan

The first step was to analyse the window of opportunity in the master schedule, which was defined by placing of topping slab (predecessor) and the start of roof activities after risers were installed. We worked with the electrical and mechanical superintendents also to confirm the installation rhythm, since they were planning to share the same crane. Figure 2 shows the difference between the schedule proposed by the general contractor and the confirmed schedule taking into account the optimized crane utilization.

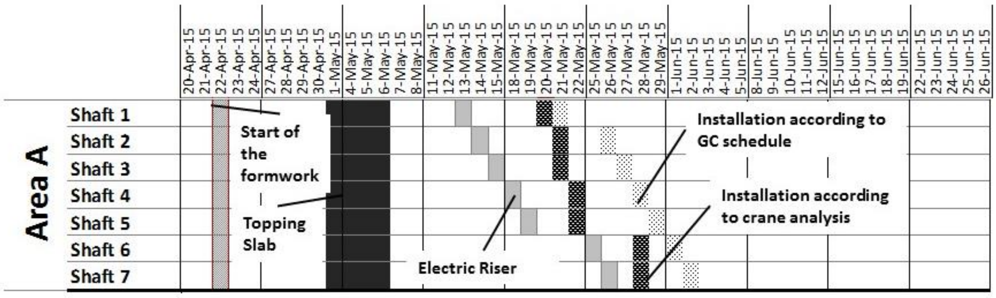

Figure 2: Details of the installation schedule, according to the crane utilization

b) Creating a fabrication plan

The second step was to take the information from the fabricator regarding lead-time and how many risers could be produced concurrently. Each riser should take 5 workdays to be produced and there was enough room for producing two of them concurrently. This was the data used in the first scenario for production, as shown in Figure 3. As it is possible to see in the LOB, the difference in the rhythm of field installation and the rhythm of fabrication, lead to a huge amount of riser, which would need to be stored.

For this reason, the HVAC contractor decided to rent a warehouse so that they could buffer the fabricated risers avoiding the uncertainty of the construction site. The idea was to have a backlog for the start of the installation process. The problem in this strategy was that it required the fabrication to start 15 weeks before the installation. However, at this time, the client have not decided yet about the insulation material of the riser and, therefore, the design could not be released to fabrication. There were also some space constraints, since the warehouse was able to store 20 risers, while the total accumulated in this scenario was 32 risers.

The second scenario developed for the fabrication of the risers, simulated a larger capacity in the fabricator. This scenario could be achieved if the fabricator build more capacity, however the need for training new people for welding is still an issue at that time. Figure 3 shows that the fabrication could start only 5 weeks before the installation. In this case, the beginning of the formwork of the topping slab could be set as a trigger for the fabrication, so it would be possible to make the fabricator react according to what was happening in the field. The amount of risers that need to be stored would be much lower, a maximum of 20 risers, which is within the capacity of the warehouse.

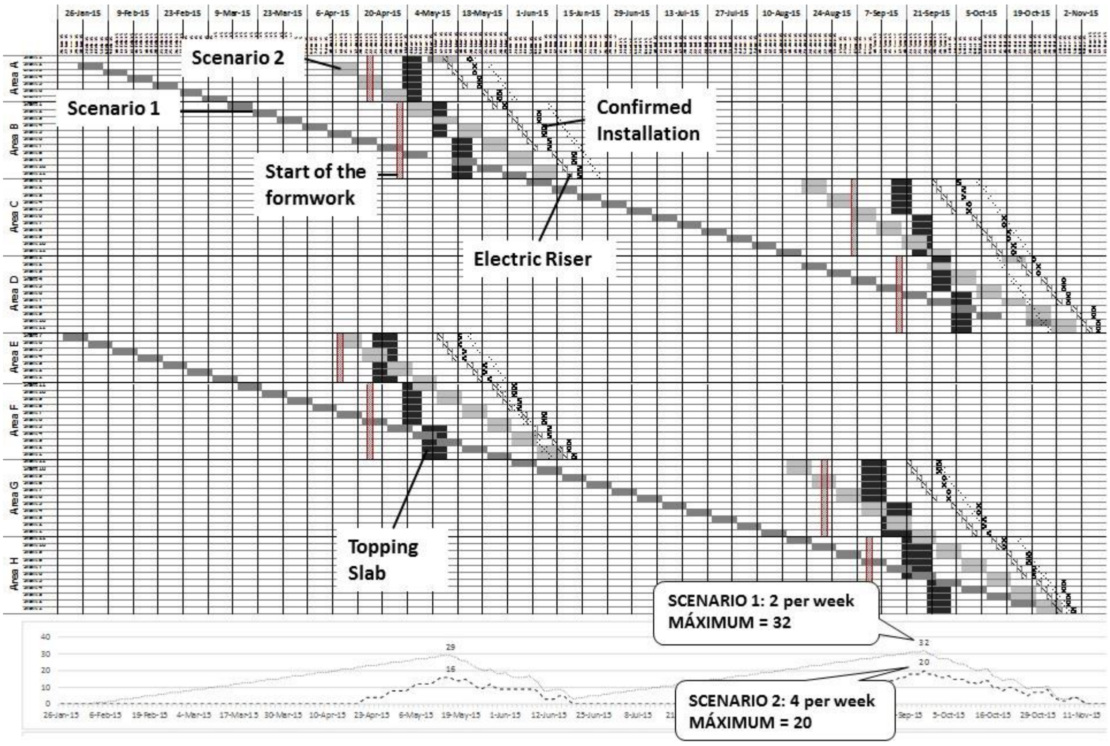

Figure 3: Scenarios for the fabrication

c) Defining the mix of production

An important characteristic of the riser is its modularity. There are five different types of risers, two of them are one-of-a-kind, while the other three types can be used interchangeably in the project. Therefore, the third step of the analysis was to examine the mix of production, for fabrication. Figure 4 shows the different types of risers and how they are distributed in the project. Because of its modularity, the risers have fewer chances to suffer with the matching problem, as discussed in Tommelein (1998), and Sacks et al. (2003). The production can easily deal with changes in the project sequence, without delaying the installation.

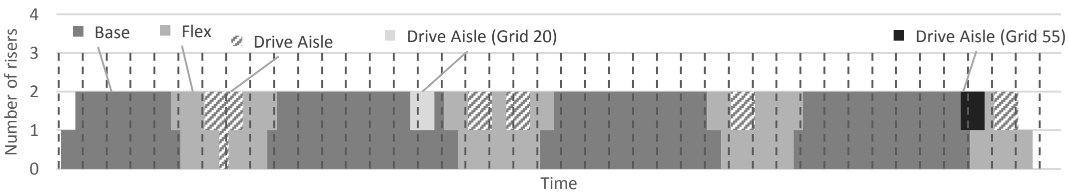

Figure 4: Riser Types / Production mix

d) Establishing a feedback mechanism

The biggest challenge we faced in this project was the constant changes in the schedule. In order to establish a feedback mechanism we tried to link fabrication plans to critical activities in the job site to facilitate matching fabrication rate with site demand. In the case of the risers, we observed that the topping slab could provide us a trigger for fabrication, e.g. when topping slab in Area A starts, we should be done fabricating risers for Area A and start fabricating Area B.

AHU

The Air Handling Units (AHU's) regulate the air circulation in the HVAC system. There were 90 units in the project. The critical part of its production was the storage constraints. The AHU's should be produced and sent directly to the site for installation. The general contractor also required that the wiring from the automation system to be installed in the fabrication facility, which could affect the lead time of the final assembly.

The AHU's contains different types of components such as fans, filter racks, soundproofing systems, and dampers. The fabricator was able to produce the final assembly in 1,5 – 3 days, and could produce up to 16 units concurrently in the 8 cells of the plant. However, the production of the components could take up to 8 weeks, and there was not much room for design changing, since the design should be delivered 16 weeks before the final assembly. Given this, there was a need to send the designs early in the process, but the final assembly could be postponed to the last responsible moment.

Differently from the risers, there are almost 20 different types of AHU's, what makes it more important to confirm the production of the unit that can be installed in the field. Because of the time required for the fabrication of the components, even decreasing the number of units in the final assembly, there is a need to produce the same number of components concurrently. Moreover, making the final assembly right before the installation avoid spending resources in handling the units for a storage place.

a) Creating an installation plan

The first step of the analysis of the AHU's was to consider the installation as planned by the general contractor. However, in this case there would be a need to use more than one crane by the subcontractor in each released area of the building. We revised the schedule with Superintendents, taking into crane use, as a means of defining installation dates. This scenario can be seen in Figure 5.

b) Creating a fabrication plan

The fabrication plan then was developed based on the installation plan. We pulled back the activities from final assembly of components, to fabrication of sub-assemblies and included finalization of detailed drawings to support fabrication.

c) Establishing a feedback mechanism

The short lead time of the final assembly, together with the large capacity of the fabrication plant made it possible to link the start of the final assembly to the predecessor of field installation: the waterproofing activity. Based on this information, the factory could better deal with stock issues by keeping the equipment as subassemblies, i.e. easier to store than the final AHUs.

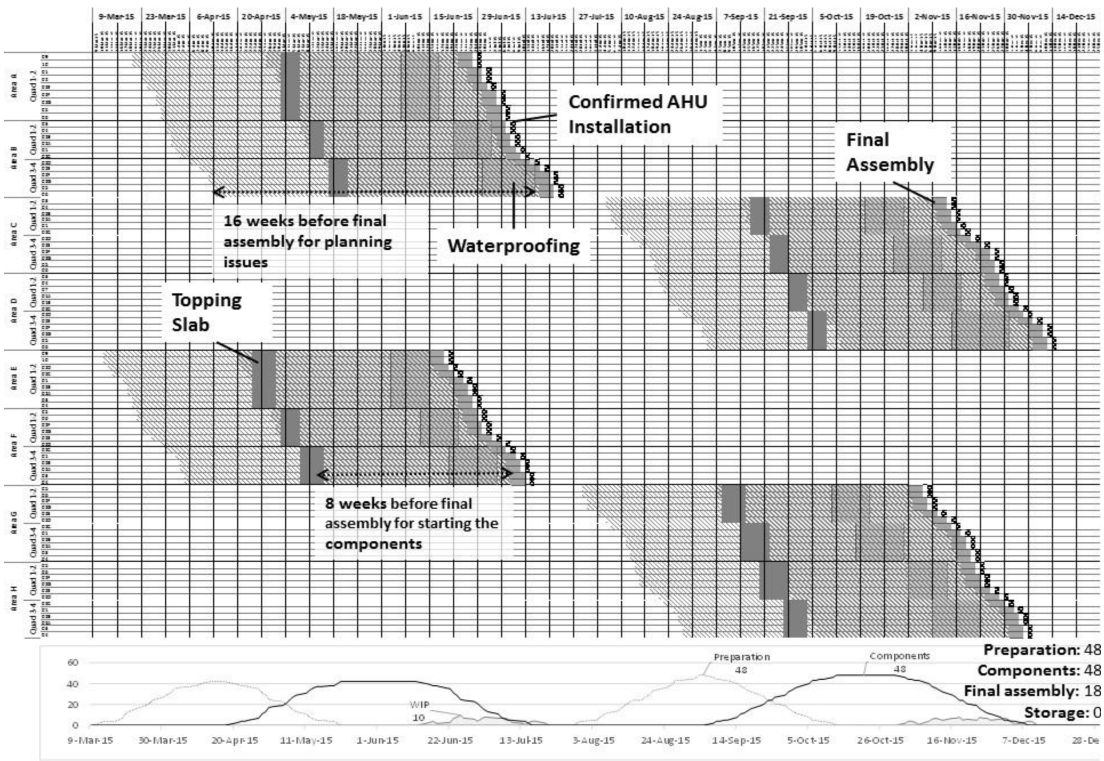

Figure 5: Scenarios for the AHU's production, according to the crane use

PENTHOUSE

The Penthouse was the most challenging installation area of the project for the mechanical contractors. In that area, the window for installation starts after the waterproofing of the slab, and finishes when the structure of the roof starts. The structure of the roof was a steel structure that would physically lock the installation work in the level, and makes it unfeasible for further loading. The level of detail of the general contractor schedule was low, considering a large batch of installation spread along a certain amount of time.

Therefore, like in the previous analysis, after defining the window, the following step was to confirm the installation dates according to crane and sequence constraints. Figure 6 shows the confirmed days of installation, and the number of cranes required in this process. By postponing the beginning of the installation of the mechanical equipment in the penthouse, it was possible to assure a more uninterrupted flow of installation, which could also benefit the fabrication, as seen in the case of the AHU's and the fabrication of the ductworks of this area as well.

The representation of the required rhythm of installation for the penthouse ductwork allowed the fabricator to accommodate that demand in their shop. The analysis also facilitated the identification of logistic challenges due to the shared use of the crane among the different activities of the subcontractors, and also due to interaction between the subcontractor crane and the one from the glass installer.

The analysis of this area of the building was also a source for the refinement of the AHU`s installation analysis, since the first confirmation of the installation dates were made, according to the main logistics constraints. As the project is under construction, there is a need to make new confirmations in the course of its development. This analysis was an important starting point for this understanding.

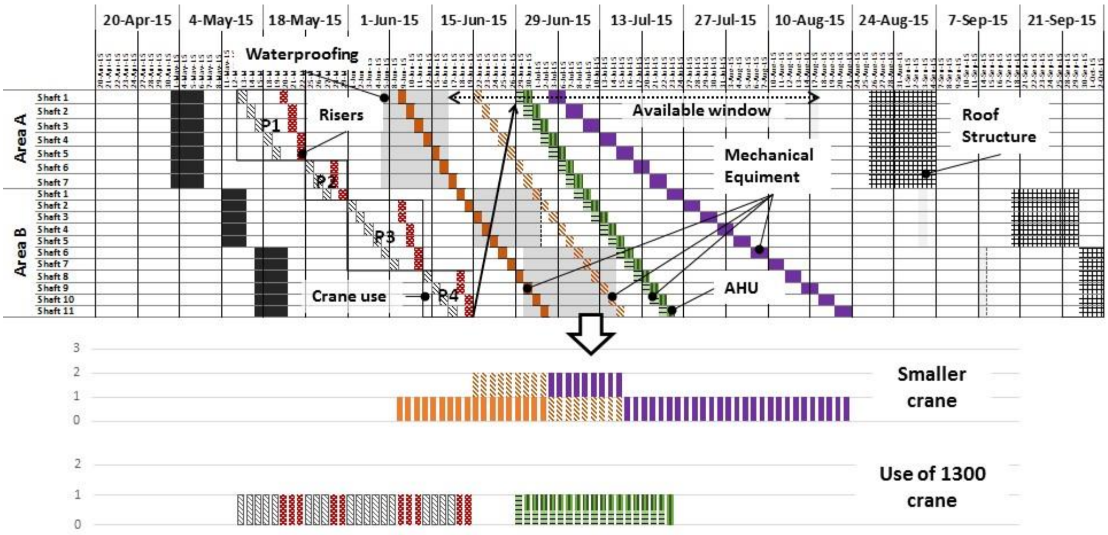

Figure 6: Penthouse analysis

CONCLUSIONS

This paper attempted to develop a planning procedure to facilitate the integration between off-site fabrication and on-site installation of ETO components by a mechanical contractor in a large and fast pace construction project. Due to changes in schedule, especially schedule compression through time, it was not clear to all project participants the demand for fabrication for all the different components under the responsibility of the HVAC contractor. There were changes in construction sequence, and on the installation rates, which also caused changes in the fabrication demand through time.

The procedure adopted in this research enabled different participants to understand better how the schedule was changing and the impacts that would cause in fabrication, logistics and in installation. Four steps were followed: (a) developing an installation plan by revising the schedule with superintendents; (b) developing a fabrication plan based on manufacturing capacity and site demand; (c) understanding the fabrication mix based on installation sequence; and (d) creating a feedback mechanism to update fabricators about the current status of the job site and forecasting changes. An important characteristics of steps a, b and c was to combine the information from the schedule and the most important quantitative analysis from that schedule, such as number of equipment used (in the case of the penthouse), or amount of product stored (in the case of AHUs and Risers)

This modelling exercise allowed the different actors in the supply chain to plan their work based on the most current data about when and in what rhythm they had to deliver their components in the jobsite. Establishing a feedback mechanism that anchors installation activities to fabrication progress enabled the team to anticipate potential impacts and threats to match installation demand. Benefits of this exercise were not only observed for the HVAC contractor, coordinating the work but also for the other members of the integrated supply chain.

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INTEGRATED PROJECT DELIVERY

Ballard G., Dilsworth B., Do D., Low W., Mobley J., Phillips P., Reed D., Sargent Z., Tillmann P., Wood N. How to Make Shared Risk & Reward Sustainable. In: *Proc. 23rd Ann. Conf. of the Int'l. Group for Lean Construction*. Perth, Australia, July 29-31, pp. 257-266, available at www.iglc.net

HOW TO MAKE SHARED RISK AND REWARD SUSTAINABLE

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ABSTRACT

This paper is about restoring confidence in shared risk and reward. In such projects, characterized by multiparty contracts, clients bear the risk of costs exceeding budgets and the project's design professionals and constructors risk doing the work for no profits. A small chance of either occurring might dissuade the parties from embracing shared risk and reward contracts. In a recent study by the authors, of four shared risk and reward projects, one exceeded budget. The client paid 6.4% more than expected and the risk pool members made no profit. Adding other shared risk and reward projects on which the authors companies have worked, the failure rate was 15%. Compared to traditional practice, clients may have received value for money even on these failed projects and so want to continue shared risk and reward, but may be unable to attract more experienced companies in the face of this probability of profit failure. The objective of this paper is to identify the factors that contributed to the failures and to propose counter measures to prevent reoccurrence. Failure to follow target value design principles is found to be a primary contributor to cost overruns on shared risk and reward projects.

KEYWORDS

Countermeasures, integrated project delivery, shared risk and reward, sustainability, target value design

INTRODUCTION

In May of 2010, the Project Production Systems Laboratory (P2SL) at the University of California, Berkeley launched a Target Value Design (TVD) Research Group with

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the financial support and participation of twelve member companies. These companies included a general contractor, an architectural firm, various engineering firms (structural, mechanical, electrical, controls), and various specialty contracting firms. The objective of the research project was to learn how to better execute TVD by examining five healthcare projects, four of which were Integrated Project Delivery (IPD) and the fifth, a public sector project, prohibited by state law from signing multiparty contracts, attempted to achieve desired behaviors and outcomes through shared incentives and was considered to be IPDish. Of the four IPD projects studied, one failed to hit its target cost, resulting in the client paying 6.4% more than planned and no profits for the design and construction firms in the risk pool.

A poll of this paper's authors found that the failure rate on completed IPD projects on which their companies worked was approximately 15%, with 4 of 26 projects failing to meet cost targets, and the risk pool companies failing to make any profits. On these same projects, clients reported no loss in value delivered as regards functionality, capacity, or quality, and paid less than 8% more than the target cost for the project. There have been many more IPD projects than those in our sample, but if the actual probability of failure is close to or greater than the 15% we found, shared risk and reward is itself at risk. Clients may continue offering such multiparty agreements, but will likely fail to attract the most capable and experienced firms.

More comprehensive reports on the TVD Research Group's work will be forthcoming. This paper is a report of the Group's study of that failed project and countermeasures proposed to prevent reoccurrence of such failures. We believe that shared risk and reward can be sustainable, delivering value for all parties, if TVD and IPD principles and methods are understood and put into practice. In accordance with lean principles, that belief and these countermeasures need to be tested—a task for future research.

Following this introduction, there is a section briefly explaining TVD and IPD, then a description of the failed project and the team's analysis, followed by proposed countermeasures, a conclusion, acknowledgments, and references.

TVD AND IPD

TVD is a managerial practice that has its origins in the Target Costing method, a strategic approach for managing product profitability that emerged in the manufacturing industry in the 1980s (Cooper and Kaplan, 1999). A fundamental characteristic of this method is viewing cost as an input to the product development process instead of an output.

In the U.S., anecdotal evidence suggests that, to date, over 100 TVD projects have been completed. Its implementation has led to significant improvement in project performance. Sutter Health reported in August 2012 that their first 22 lean projects (involving at least Last Planner and TVD) all completed within time and budget, averaging 3.4% under budget (Conwell, 2012). Roughly half the 22 were done under Sutter Health's Integrated Form of Agreement, a multiparty contract with shared risk and reward. UHS reported that of 46 IPD projects that followed some of the principles of TVD, only two had exceeded the budget, with the largest 7.25% over budget (Seed, 2013).

TVD can be used in a variety of different contractual environments, one of which is IPD (Integrated Project Delivery). IPD designates contracts signed by multiple parties, including the client, and involves shared risk and reward for the key members of the project team, those in the risk pool, whose costs of work are reimbursed. The client risks paying costs in excess of project budgets (target cost) and risk pool companies risk doing the work for reduced or zero profit.

DESCRIPTION OF ANALYZED PROJECT

This section provides a brief project description and a timeline of key events. The factors that contributed to the project completing over time and over budget are described. The method used to conduct this analysis was the case study, which has distinct advantages over other research methods when a “why” question is being asked about a contemporary set of events over which the investigator has little or no control (Yin, 1994). Using both qualitative and quantitative data, case studies allow an investigation to retain meaningful characteristics of real-life events, providing an in-depth understanding of phenomena and allowing the investigation of causal relationships.

To assure internal validity of this single case study, data collection procedures included different sources of evidence: (a) an extensive evaluation of project documents, including the project’s risk and opportunity log, contract, validation study, floor plans, Owner Architect Contractor (OAC) presentations, and cost estimating documents; (b) multiple interviews with over 30 different project participants; and (c) a series of workshops with project team members to discuss research findings and develop countermeasures.

The project was a 250,000 ft2 patient care pavilion. It was an addition to an operating hospital and was connected on three sides to existing buildings. The 13-storey pavilion included 238 medical/surgical and acute rehabilitation beds with 11 floors above grade and 2 floors below grade. The EMP (estimated maximum price; Darrington and Lichtig, 2010) for the risk pool member companies was $251 million. The project was completed 6.4% over budget, with no profits for the twelve risk pool member companies that signed the Integrated Form of Agreement (IFOA, Lichtig, 2006).

DESIGN PHASE

In December 2007, the scope of the project was increased by owner decision, resulting in an increase in the total target cost from $219 million to $276 million, which included owner costs for which the risk pool member companies were not responsible. In target value design, a target scope and cost are set by mutual agreement of client and risk pool member companies, then design is steered to those targets. Steering is informed by tracking expected cost against target cost. At first glance, Figure 1 appears to have served that purpose, but closer examination revealed that the target scope for the project was not fixed until the commitment to an Estimated Maximum Price (EMP) in July 2010.

Although no further changes in the target cost were made during design, there were numerous substantive changes in project scope. The owner was exploring alternative ways to deliver its Master Facility Plan, of which the Patient Care Pavilion was one part. The project team was continuously challenged to provide design and pricing for different options. With no certainty what portion of those budgeted costs would or would not be the responsibility of the team to capture in the EMP. The big jump at Dec 08 and decline at May 09 is an example of that effect from the $50M 1000 car parking garage being included/then excluded from reports and estimates.

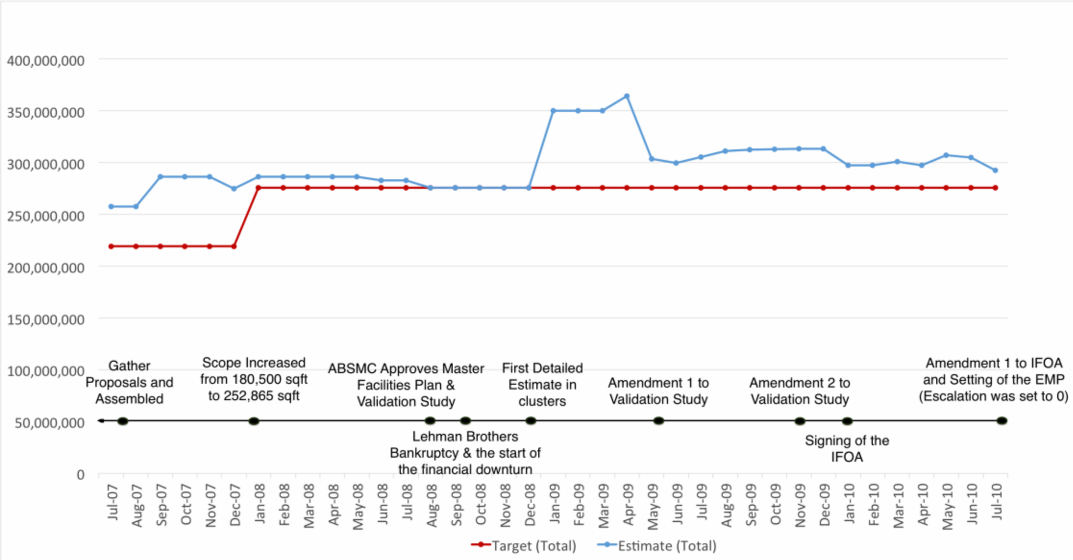

Figure 1: Comparison between Expected Costs and nominal Target Cost in Design Phase

There was a sharp decrease in the estimated cost between Nov ’09 and Dec ’09. This may coincide with efforts to reduce the gap between expected and target cost to a more “manageable” number just prior to signing the IFOA. (At the signing of the IFOA in Jan ’10, the gap between target and expected cost was ~$21 million or ~8% above the target cost.) One instance of reduction in expected cost: $10 million was removed from the expected cost, allegedly in expectation of improved productivity as a result of detailed modelling. There does not appear to have been any analysis linking cause to desired effect, and in fact field productivity did not improve. It may be that risk pool companies were trying to avoid cancellation of the project and/or to assure their eligibility for future projects with this client—what Axelrod (1984) referred to as ‘the shadow of the future’, arguing that current cooperation requires expectation of a shared future. However, in this case, exacting such concessions violates both the spirit and the letter of the contract. If this practice was followed on all projects, companies invited to join a project risk pool could expect to risk not only their profits but some share of cost overruns. Another instance of the same kind occurred when expected cost dropped again between June ’10 and Jul ’10. The IFOA team decided to set the future escalation of the project at $0 given the extent of committed costs and the economic climate at the time. This decision removed $15.5 million from the expected cost of the project.

CONSTRUCTION PHASE

In Figure 2, the original EMP of $243 million, not total project target cost, is compared with expected costs during the construction phase. (Note that subsequent owner changes increased the contractual EMP to $251 million.) Although there were considerable savings from value engineering innovations (e.g., spending $200K to redesign the pile system to get over $1 million in savings), overall the cost increases exceeded the cost savings.

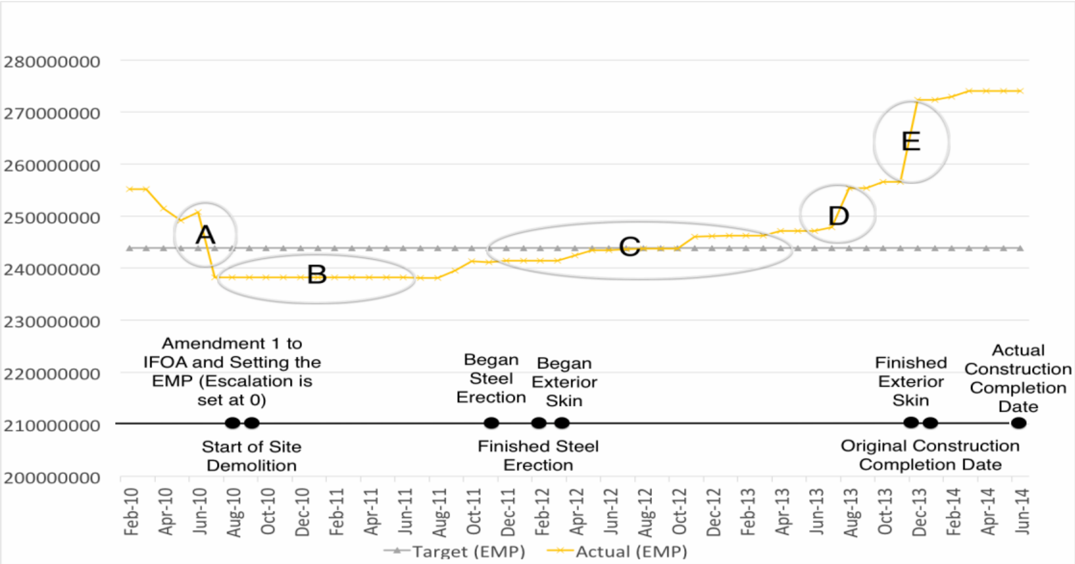

Figure 2: Comparison between EMP and Expected at Risk Costs in Const. Phase

The major changes in expected cost relative to the EMP and their respective explanations were:

- A: The decrease was mainly due to the removal of escalation from the project and the adjustment in expectation of improved productivity.
- B: After the completion of steel erection, the project seemed to be on track to finish within the EMP. However, problems with the exterior skin surfaced in July ’ 12 and persisted until Nov ’ 13. The original schedule anticipated that the exterior skin be finished in ~6 months but the actual schedule showed that they were on-site for over 1 year.
- C: The drywall trade had increased costs from working overtime to make up the schedule, jumping around due to missed details or not being able to do them in the field, and impacts from the exterior panels not being signed off in time. As a result, much of their work was out of sequence.
- D: The electrical and mechanical trade partners also had overtime work that contributed to the cost increases. The structural and architectural group had a greater amount of construction administrative cost than they had previously anticipated.
- E: Construction completion, scheduled for Dec ’ 13, was anticipated to be 4 to 6 months late. The team had not factored the increase in general conditions into their cost projections. After including the cost of the additional general conditions, the project cost increased dramatically.

There was a sharp increase in costs toward the end of construction. The problems that happened during that period were analyzed and their root causes investigated by the team. While some causes seemed to be out of the team’s control, others perhaps could have been avoided and represent important lessons learned about the application of TVD on IPD projects.

One cause of the cost overrun: the approved design for the building envelope was not complete or constructible at the point when fabrication was needed.

Responsibility for the building envelope, including seismic joints, belonged to a company not signatory to the IFOA, bringing extra challenges to problem solving, including conflicting incentives and delayed communication. For over a year (from early 2012 to mid 2013), the architect, structural engineer, contractor, subcontractor, and subcontractor's sub tier detailer struggled to coordinate the design of the 100+ unique seismic joints. Many critical issues were identified where the conditions of satisfaction for seismic requirements and fire rating could not be met given the existing conditions at the time (structural steel and concrete decks were already poured). The more the design was investigated, the more issues were found. The seismic joint manufacturer struggled to provide an acceptable solution and finally brought in a specialty designer one full year after permit. This had a drastic impact on site operations, delaying execution of several activities.

Other problems occurred because installers were not involved in early design stages, which caused constructability and inspection problems that also contributed to delays, rework and increased project cost. What's more, the project contingency was set at the same level as for a standalone hospital constructed in the same area and time frame, despite the differences in complexity. Beyond the challenge of connecting the patient care pavilion to three existing buildings, there were numerous constraints that might reasonably have required a larger contingency, including differences in the hospital ownership structure and behavior which impacted owner speed of decision making.

Finally, the lack of shared governance during the construction period concealed productivity problems faced by some contractors, and hindered the constant analysis of changes in expected costs through time. The project team also failed to implement accurate and transparent productivity measuring systems which would have allowed the team to identify areas of the project that were underperforming. Scrutiny is much more common when projected costs are above the expected but rarely done when projected costs are below the target. This tendency may well have contributed to late realization of the magnitude of the cost overrun.

COUNTERMEASURES

To reduce the risk of project failure, the following principles and practices are proposed. Following these is recommended for all IPD/TVD projects, and are not intended exclusively for the case study project:

1. Commit the entire project team, owner included, to delivering what the owner needs within their constraints with a fair profit to the risk pool members. Customers must commit to the economic success of their suppliers, and suppliers must commit to delivery of customer value. Only projects that achieve both objectives are truly successful. Sustainability of the delivery method must not be sacrificed to the pursuit of excessively risky targets. Don't be Greedy….Don't be Foolish
    a. OWNERS – Don' t be Greedy
        i. Pursue continuous improvement from project to project, respectful of the risk pool companies' need for profits.
    b. RISK POOL – Don' t be Foolish

i. What is the probability that the cost gap can be closed without reducing value delivered to the client?

2. Follow P2SL's recommended process for determining if projects are financially viable.

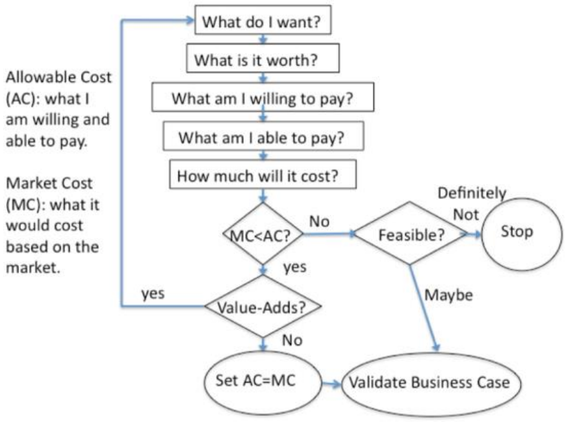

Figure 3: Determining Project Viability (Ballard and Morris, 2010)

a. Anchor target cost in allowable cost (what the owner is willing and able to pay), assess gap between allowable and market, decide if to do a validation study only if you (the owner) think the gap might be closed, validate the owner's business case only if you (the risk pool members) are prepared to accept the risk of working for free.

b. Treat validation as the first and primary assumption of risk by both owner and risk pool members, not as a mere cost estimating exercise.

c. Should Allowable Cost be Calculated & Shared?

d. If an owner does not know the allowable cost for a project, they can't determine when the project is financially viable. And if they want the advantages of a shared risk and reward project, they can't judge viability by themselves because they're asking the risk pool members to accept the risk of working for free. An owner can pose a target cost without revealing its relationship with allowable, but may conceal the extent of risk. Suppose the target cost is 10% below the market benchmark, and the allowable cost is 5% below the expected cost (Figure 4). If the target cost becomes budget, shared savings starts at 10% below market. If the allowable cost were to become the budget, shared savings would start at 5% below market. The best advice is for the owner to share their allowable cost, so the team can see what's needed to make the project viable and what options exist for managing risk.

Figure 4: Relationship Between Market, Allowable, and Target Cost

    e. Keep close track of the scope of work. When scope is unclear, cost estimates are inaccurate. Revalidate when scope is changed.

3. Having the people who will actually design and construct the project help clients work through alternatives to get to a firm scope is one of the advantages of IPD. However, the act of validation is an assessment of risk and assumes the scope of the project is relatively firm so risk can be assessed relative to targets. Consequently, it is advisable to revalidate when scope is changed.
4. Involve the right people at the 'earliest responsible moment' to maximize the impact on design and constructability.
    a. Engage the craft workers/supervisors who will actually build the project. Otherwise, if only estimators and schedulers are involved, you will discover too late that the design is not 'right'.
    b. Assign owner representatives with decision-making authority. This can be a problem when the owner/users do not actively participate in the management of the project, in which case the owner representatives who do participate are compelled to defer some decisions in order to involve the users.
5. Have owner and risk pool members decide what companies and individuals to add/remove to/from the project team.
    a. This is standard practice for some, but should be standard practice for all in order to match shared governance with shared risk and reward. Timing is critical—not too soon and not too late.
6. Exclude from the risk pool only companies whose work can be decoupled from the rest of project delivery or where risk is small.
7. Move money and scope across traditional trade and contractual boundaries to achieve better project outcomes. Even though IPD contracts make this possible, sometimes it still does not happen, or happen at the right time; e.g., releasing excess funds from one TVD cluster to another that needs the money.
8. Require the same level of evidence for cost reductions as for cost increases.
9. Maintain shared governance throughout project execution. Shared risk and reward calls for shared governance, a role many design and construction professionals find challenging. Experience has taught the necessity of radically changing their role, especially as regards oversight of the performance of fellow professionals. There is also a tendency for projects to revert to traditional practice during the construction phase, after commitment to an EMP or GMP, when the GC again takes on their traditional role.

10. Use transparent productivity measuring systems to allow the team to identify areas of the project that are underperforming.
11. Faced with cost pressure, too often the reaction is to stop spending, disregarding opportunities to reduce future cost by spending wisely now. For example, decisions may be made to reduce the scope or level of detail in modeling in order to reduce cost, and thus run past the opportunity to reduce future fabrication or installation costs.

CONCLUSIONS AND FUTURE RESEARCH

For shared risk and reward to remain a viable project delivery option, it must be sustainable. That means that owners get value for money and at-risk service providers make an acceptable profit. There will inevitably be exceptions, but the industry can learn from its own experience how to reduce such exceptions. This paper has presented a case study of one shared risk and reward project that clearly failed to deliver acceptable profits to risk pool member companies, cost the client more than budgeted, and was delivered late. Countermeasures have been proposed, based on the study of both successful and failed projects. The countermeasures consist of following IPD and TVD principles and best practices, many of which have been previously identified, but are not consistently observed in practice.

All countermeasures are elements in Plan-Do-Check-Act cycles. A countermeasure (PLAN) such as those proposed in this paper must be tested in practice (DO) and its effectiveness evaluated (CHECK). If not fully successful, revisions are made in the countermeasures and they are tested again, until a version is found to be effective, in which case, that is deployed as a standard practice (ACT). Another area for future research is analysis of shared risk and reward contracts for their consistency with current theories of the conditions underlying cooperation and competition, of which one of the principal authors is Robert Axelrod, cited previously.

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COMPARING THREE METHODS IN THE TENDERING PROCEDURE TO SELECT THE PROJECT TEAM

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ABSTRACT

Normally, the selection of a project team is based on Weighting Rating Calculating (WRC) and often relies on only one factor; the cost factor. WRC is a method that allows for assessing multiple factors easily but the bidders' differences may not be highlighted, since factors are weighted independently of the attributes. A more recent concept, which is based on WRC, is Best Value Selection (BVS). BVS is a method where the best value score is calculated as the bid price divided by the qualification score. Choosing By Advantage (CBA) is a multiple-criteria decision-making method based on advantages of alternatives. Advantages are compared in order to decide the importance of them. We argue that CBA provides further benefits for helping public clients to differentiate between bidders. A case was constructed, based on the tendering procedure of the project Mission Hall, to exemplify the differences of the three methods for bidder selection in the context of public tendering requirements. This paper presents the analysis and discusses the results of the simulated case.

KEYWORDS

Best value selection, choosing by advantage, weighting rating calculating, selection, tendering procedure, project team.

INTRODUCTION

Traditionally, in a public tendering procedure the selection of the project team is only based on lowest cost, and technical and management qualifications are not involved. Especially in complex, uncertain, and cost-intensive projects the selection by lowest cost can result in conflict situations and lead to protracted disputes. A tendering procedure by "lowest bid" tends to create an unhealthy price competition, resulting in a working environment where bidders hide knowledge and information in order to

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make claims to get money out of the project to survive (Schöttle and Gehbauer, 2013). This leads to waste in terms of conflict resolution and legal procedures.

A complex and uncertain project requires real collaboration for lasting success. However, there is no incentive for bidders to work collaboratively under low bid tendering. So, why do public clients mostly use only price to select the team? Obviously, selection based on cost is clear and simple. There is no room for interpretation and misunderstanding. However, the lowest bid does not result in the best team. When project complexity increases, the tendering procedures employed need to change so that the needs and requirements of the project will shape the decision. Using collaborative approaches like Integrated Project Delivery (IPD) or project alliancing requires a tendering procedure based on competence (Lahdenperä, 2009) and value.

In decision theory different methods to choose between alternatives exist. This paper will compare three methods: Weighting Rating and Calculating (WRC), Best Value Selection (BVS), and Choosing by Advantages (CBA). WRC is a method that assesses multiple factors easily but the bidders' differences may not be highlighted, since factors are weighted independently of the attributes of the bidders. WRC is a method which is widely used in tendering procedures with multiple factors. BVS uses the ratio of value to bid price to select the winning bid. CBA is a multiple-criteria decision-making method based on comparing advantages between alternatives. CBA is not used in the tendering procedures yet, but it could be beneficial in helping owners better discern relative value between proposals.

First, the three methods and the requirements of the tendering procedure will be briefly explained. Then we will illustrate the differences between these bidder selection methods by evaluating each method based on a real case.

RESEARCH METHOD

This research builds on previous research comparing CBA with WRC for selecting building systems and materials (Arroyo, Tommelein and Ballard, 2013; 2014a; 2014b). In those cases CBA demonstrated its benefits. However, research on comparing these two methods has not included selecting a project team, to the best of our knowledge. In addition to CBA and WRC, another procurement method is BVS. For example the University of California, San Francisco (UCSF) used a modification of BVS to select the project team for Mission Hall. Therefore, we extended our research and added BVS to our analysis.

The research questions in this paper are:

- What are the differences between WRC, BVS, and CBA for selecting a project team and how those differences may affect the selection of a project team?
- How objective are the results?
- Which method would be best for selecting the project team?

In this research we first conducted a literature search comparing WRC, BVS, and CBA. Second, based on the tendering procedure of the real project Mission Hall we constructed a case to compare the methods in the context of bidder selection. Finally, we discuss the results and conclude.

THEORETICAL OVERVIEW

This section gives a brief overview over the requirements of public tendering procedure as well as of the WRC, BVS and CBA methods. Before explaining the methods, we have to clarify the term ‘alternative’. In case of selecting a project team, the alternatives are bidders themselves and therefore the project teams, each of which submits technical and price proposals. As the proposals of each team will be evaluated based on identified factors and criteria the proposal itself can also be defined as an alternative.

REQUIREMENTS OF TENDERING PROCEDURE

Public clients are bounded by regulations, which require a fair competition. Therefore, to select the project team objectively the factors and criteria need to be defined clearly in advance (before tendering starts). More general issues include the competence of the client to manage procurement and to build a project team. Thus, the method of bidder selection needs to be practical and easy to understand. These aspects will not be considered in this paper. We will start from the point where factors have been defined for the tendering process.

WEIGHTING RATING AND CALCULATING (WRC)

WRC (often also named as weighted sum, scoring system, ranked scoring, utility analysis) is a much-used decision-making method. In WRC, the weighting of factors and attributes is done directly and indicates the importance of each factor for the decision maker. The factor weights must sum to 100%. The WRC method can be summarized in the following steps: (1) Identify alternatives (bidders). (2) Identify factors and criteria for evaluation. (3) Weigh factors. (4) Rate alternatives (proposals) for each factor. (5) Calculate the ‘value’ of each alternative (proposal) and come to a final decision. Figure 1 shows the steps to apply the WRC method (Belton and Stewart 2002; Arroyo, Tommelein and Ballard 2014b).

Compared to the private sector, in public tendering the number of bidders is reduced by pre-qualification rather than identification by free choice.

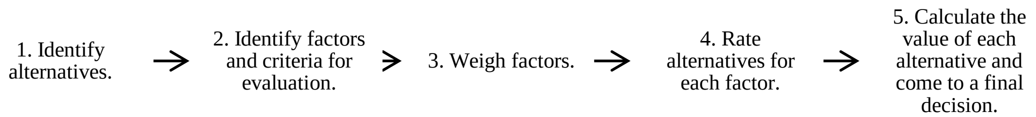

Figure 1: Steps of WRC method

BEST VALUE SELECTION (BVS)

BVS (or Best Value Scoring Analysis or BVSA) is a method, where the lowest responsible bidder is selected by ‘value’. The method is based on WRC, but differs in the evaluation of the bid price. In WRC the bid price is a weighted factor, whereas in BVS the bid price is a separate factor and the best value score is calculated as the bid price divided by the qualification score. The smaller the ratio between bid price and score the better the proposal (value-for-money). The BVS method can be summarized as WRC decided by calculating bidder price/value score (see figure 2). Abdelrahman, Zayed, and Elyamany (2008) state that BVS rewards innovation, because the “optimal combination of price and technical capabilities” will be obtained, if “the right choice of the evaluation factors […] and their relevant weights” is assessed.

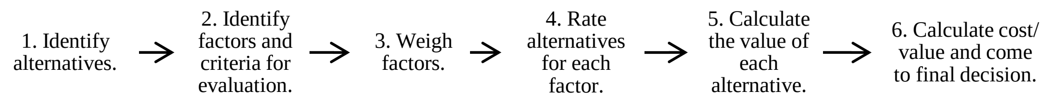

Figure 2: Steps of BVS method

CHOOSING BY ADVANTAGE (CBA)

CBA is a system of making decisions using well-defined vocabulary to ensure clarity and transparency in the decision-making process (Suhr, 1999). According to this, it is important to identify which factors will reveal significant differences between alternatives, not what factor (in the abstract) will be important in the decision.

In this research we used the CBA Tabular method for moderately complex decisions. The CBA Tabular method can be summarized in 7 steps. (1) Identify alternatives (bidders) likely to yield important advantages over other alternatives (bidders). (2) Define factors to evaluate attributes (characteristics) of alternatives (technical proposal). (3)Agree on the criteria for each factor. Criteria can be either a desirable (want) or a mandatory (must) decision rule. (4) Summarize the attributes of each alternative (technical proposal). (5) Decide the advantages of each alternative (bidder). (6) Decide the importance of each advantage. Here the owner must explicitly state their preferences for the advantages. The owner selects the paramount advantage, which is the most important advantage and is usually assigned 100 points. The paramount advantage is used as a reference point to compare to other advantages. Then the owner assigns importance to other advantages by comparing these to the paramount advantage. It is not assumed that advantages are independent; therefore, similar advantages can be grouped or one advantage can be assigned zero importance if the client estimates it does not provide any additional 'value'. The importance of advantages for each alternative (proposal) is summed. Finally, (7) Evaluate cost data summarizes the seven steps (see figure 3).

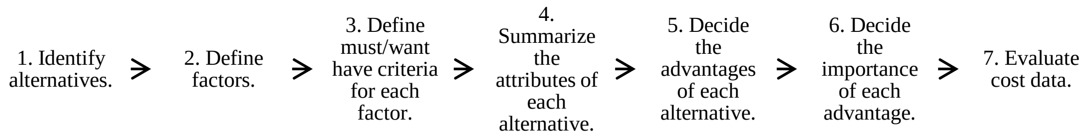

Figure 3: Steps of CBA method

CASE BACKGROUND

The simulation is based on the UCSF academic office building named Mission Hall, located at the Mission Bay campus in San Francisco. The 264,000 square foot (sf) seven floor building was opened in October 2014. To select the project team UCSF used BVS with elements of CBA, as the performance criteria contain judgments about their relative importance, which are reflected in the scoring. The tendering consisted of a pre-qualification process and a bid process. After the pre-qualification process three Design-Build (DB) teams were identified. The bid process began in April 2012. During the bid process each team developed a proposal based on the Bridging Documents, which consisted of a project program, design criteria package, and a comprehensive tiered performance specification for the building. Proposals were rated using seven performance categories (including 267 performance criteria with a minimum requirement, 39 possible Tier 2 criteria, and 20 possible Tier

3criteria). The performance criteria are: A Quality Work & Learning Environment, A Model of Architectural & Urban Design, A High Performing Building, Environmentally Sustainable, Durable & long-lasting, Efficiently Serviced & Maintained, Quality & Clarity of Project Plan. By achieving Tier 2 and Tier 3 teams are able to add value to important technical criteria as described by UCSF. The required criteria can be defined as 'must have' criteria and Tier 2 and 3 as 'want to have criteria'. Structural and energy performance were weighted higher than other technical criteria on the. Overall quality of design of the workplace was equal to the entire technical half of the scoring. Based on the performance criteria evaluation, teams could achieve up to 6,000 points. For the first two categories the bidders could achieve 1.500 points. For category three till seven a maximum of 600 points were possible. The difference of maximum achievable points can be seen as weights. The more points on offer, the more important the category was for UCSF. During the bid process UCSF decided to change the scoring system to ranked scoring, where the top-ranked bidder gets the maximum achievable points, the bidder ranked on the second place 2/3, and the third ranked bidder 1/3 of the maximum possible points per category. This fact will not be used for the simulation.

The project team was selected in July 2012 and after two months of pre-qualification and three months for the bid process. Table 1 shows the calculation leading to the award. As UCSF stipulated that the full sum would be spent and requested bidders to maximize building design quality and technical performance for the stipulated sum, bidders did not have the option to propose a lower price. All teams had to work with the stipulated sum, which was written into the bid form by UCSF. Thus, the effect of price was neutralized, and the competition became one of which proposal could provide the most meaningful advantages.

Table 1: Final Award Calculation of Mission Hall

Team	Points	Target Cost	Cost/Quality Point
A	2,400	$ 93,800,000	$ 39,083.33
B	5,800	$ 93,800,000	$ 16,172.41
C	4,200	$ 93,800,000	$ 22,333.33

CONSTRUCTED CASE

To compare the methods WRC, BVS, and CBA we constructed a case and simulated the case with each method. As described earlier, the case is based on (but not identical to) the tendering procedure used for Mission Hall. First we modified the background case in terms of the number of performance criteria to simplify the simulation. Table 2 shows the 18 factors which are used for the constructed case. Every factor has an identification number (ID) to represent the simulation clearly for every method. In order to simulate the price proposal, we assume the following bid prices in million $: bidder 1 submits 93.8, bidder 2 submits 92.5, and bidder 3 submits 93.7.

Table 2: Performance Criteria with identified Factors

Category	Performance criteria/Factor	Tier	ID
A Quality Work & Learning Environment	All **building interior program spaces** shall fit into the designated gross area (266,000 GSF).	R	1.A
	Set a model for the future of UCSF workplace through an **Activity-Based Workplace** tailored to the function, activities, and tools of UCSF faculty, staff, and students.	R	1.B
	Foster an **interactive**, collegial, and collaborative environment that fuses the clinical programs with dry, basic and translational research.	R	1.C
	Maximize **daylight** and views throughout the interior spaces to provide a quality experience, connection to the outside, and health & wellness.	R	1.D
A Model of Architectural & Urban Design	A network of **sight lines and passageways** linking landmarks, focal points, and open spaces, enhanced by effective way-finding devices, will streamline movement across campus and strengthen physical and visual unity.	R	2.A
	The **facade** design should be harmonious with the adjacent landscape spaces and existing buildings and contribute to the urban context. Materials, color, ornamentation, texture and composition should be cohesive and incorporate with the surroundings.	R	2.B
	Design the **building interior** to be imaginative, contemporary yet timelessly elegant, cohesive and meaningfully transparent.	R	2.C
A High PerformingBuilding	Design a building with an integrated high efficiency envelope, high efficiency **lighting** and HVAC systems that uses less than 33 kBtu/sf/year**.**	2	3.A
	Provide**Vegetated Roof**.	3	3.B
EnvironmentallySustainable	Design hot and cold water distribution system per CPC 2010 to achieve 30% **water savings**.To exceed gray water shall be filtered, purified and reused for flushing toilets and irrigation to achieve 45% water saving.	3	4.A
	Use **materials** that can be fully recycled at end of service life.	2	4.B
Durable &long-lasting	**Vibration** shall not exceed 8,000 µ-in/sec at any location under a walking pace of 75 steps/minute.	2	5.A
	The Mission Bay area has a history of unstable soil with settlement and potential liquefaction. The proposed **utility system** design must accommodate these factors and address the following considerations: 1. Minimize piping under slab 2. No electrical under slab 3. Utilities should enter building at the perimeter and a maintainable pathway should be provided 4. The design solution should include support anchorage and flexibility 5. Materials used must respond to the corrosive environment	R	5.C
EfficientlyServiced&Maintained	Provide for flexibility within the **Faculty Workspace**. Standardize sizes of room types and use a modular planning approach to support long-term adaptability.	R	6.A
	Site **lighting elements** should be of low maintenance and shall be considered to have an illumination life span of greater than 25,000 hours. The elected lighting element should also include a manufacturer's warranty on all components of the light fixture.	R	6.B
Quality & Clarity of Project Plan	Use the **Last Planner™** method of production management during design and construction.	R	7.A
	Set-based design approach to produce design solutions and to continuously improve the building and site design.	R	7.B
	Integrate a **Target Value Design** into the project.	R	7.C

After identifying factors and criteria, we established the CBA table. Table 3 shows the evaluation of the 18 factors by using CBA.

Table 3: Constructed Case - CBA Tabular method

	Factor (Criterion)	Alternative 1: Bidder 1		Alternative 2: Bidder 2		Alternative 3: Bidder 3	
A Quality Work & Learning Environment	1.A Building interior program spaces	Att.: 261,283 GSF.		Att.: 264,197 GSF, but missing some classrooms.		Att.: 258,178 GSF.	
	(The more fit between program space and designated gross area (266,000 GSF), the better.)	Adv.: Significantly Better fit between program spaces and gross area.	Imp.: 100	Adv.: Slightly better fit between program spaces and gross area.	Imp.: 50	Adv.:	Imp.:
	1.B Workplace	Att.: Visual accessibility is ad-hoc to support spaces.		Att.: Acceptable. In equal access to ad-hoc support spaces. Could be better organized.		Att.: Meets requirement. Bad breakout.	
	(The more activity-based, the better.)	Adv.: Considerably more activity-based.	Imp.: 50	Adv.: More activity-based.	Imp.: 30	Adv.:	Imp.:
	1.C Building interior	Att.: Typical floor plans have one major point of intersection for groups to collide and interact. Ground floor is separated into disparate zones without much required interaction.		Att.: Communal space and ground floor are very strong from a collaborative /interactive perspective.		Att.: Interactive. Atrium centralized with circulation and interactive spaces. Limited prefunction space.	
	(The more interactive, the better.)	Adv.:	Imp.:	Adv.: Significantly more interactive concept.	Imp.: 60	Adv.: More interactive concept.	Imp.: 40
	1.D Daylight	Att.: High amounts of natural lighting/ access to views perspective. No shading strategies.		Att.: Various glass openings, but no shading strategy.		Att.: Various glass openings with shading strategy.	
	(The more daylight, the better.)	Adv.: Significantly more amount of daylight.	Imp.: 70	Adv.:	Imp.:	Adv.: More shading strategies	Imp.: 30
A Model of Architectural & Urban Design	2.A Sight lines and passageways	Att.: Effective.		Att.: Effective.		Att.: Very effective.	
	(The more effective, the better.)	Adv.:	Imp.:	Adv.:	Imp.:	Adv.: Most effective approach.	Imp.: 60
	2.B Facade	Att.: Fits good.		Att.: Fits totally.		Att.: Fits totally.	
	(The more the design fits to the surroundings, the better.)	Adv.:	Imp.:	Adv.: Better fit.	Imp.: 80	Adv.: Better fit.	Imp.: 80
	2.C Building interior: Workplace	Att.: Meets requirement. Articulated circulation ceiling, creative use of color.		Att.: Meets requirements.		Att.: Meets minimally requirement. Limited color palette.	
	(The more timeless and creative, the better.)	Adv.: Significantly more creative.	Imp.: 60	Adv.: Slightly more creative.	Imp.: 20	Adv.:	Imp.:
A High Performing Building	3.A Light systems	Att.: 32 kbtu/sf/year		Att.: 33 kbtu/sf/year		Att.: 15.5 kbtu/sf/year	
	(The more less the kbtu/sf/year, the better.)	Adv.: 1 kbtu/sf/year less.	Imp.: 5	Adv.:	Imp.:	Adv.: 17.5 kbtu/sf/year less.	Imp.: 40
	3.B Vegetated Roof	Att.: 130 sf		Att.: 150 sf		Att.: 80 sf	
	(The more sf, the better.)	Adv.: 50 sf more.	Imp.: 10	Adv.: 70 sf more.	Imp.:	Adv.:	Imp.:
Environmentally Sustainable	4.A Water saving	Att.: 30%		Att.: 30%		Att.: 35%	
	(The higher, the better.)	Adv.:	Imp.:	Adv.:	Imp.:	Adv.: 5% more saving.	Imp.: 30
	4.B Materials	Att.: Partially addressed.		Att.: Choose not to pursue.		Att.: Partially addressed.	
	(The more recyclable, the better.)	Adv.: Slightly more recyclable.	Imp.: 20	Adv.:	Imp.:	Adv.: Slightly more recyclable.	Imp.: 20
Durable & long-lasting	5.A Vibration	Att.: 75 steps/minute		Att.: 100 steps/minute		Att.: 75 steps/minute	
	(The more steps/minuet, the better.)	Adv.:	Imp.:	Adv.: 25 steps/ minute more.	Imp.: 40	Adv.:	Imp.:
	5.B Utilities system	Att.: General responses for the utility system design provided.		Att.: Inventive way to avoid utilities under slabs. Team proposes settlement vaults within landscape areas, flexible connections, and a raised floor system for utility routing.		Att.: Narrative of compliance only, but no description of how.	
	(The more beneficial, the better.)	Adv.: Slightly more beneficial system.	Imp.: 10	Adv.: More beneficial system.	Imp.: 50	Adv.:	Imp.:
Efficiently Serviced & Maintained	6.A Faculty Workspace	Att.: Very flexible. Spaces (hard walls) are used in a very modular approach to be easily adjusted for changes. Focus rooms can be converted into huddle rooms, etc.		Att.: Little flexible. Room sizes are standardized. Irregular neighborhood modules will constrain long term flexibility.		Att.: Flexible. Spaces are standardized and designed with a modular approach. No major constraints to long-term flexibility.	
	(The more flexible, the better.)	Adv.: Considerably more flexible.	Imp.: 90	Adv.:	Imp.:	Adv.: More flexible.	Imp.: 60
	6.B Site lighting elements	Att.: Maintenance meets requirement. Life span is 25,000 hours.		Att.: Maintenance meets requirement. Life span is 30,000 hours.		Att.: Maintenance is very low. Life span is 25,000 hours.	
	(The lower the maintenance and the greater the life span, the better.)	Adv.:	Imp.:	Adv.:5,000 hours more of life span.	Imp.: 30	Adv.: Lower maintenance.	Imp.: 10
Quality & Clarity of Project Plan	7.A Last Planner™ method	Att.: Demonstrate full understanding.		Att.: PPC during construction only.		Att.: Proposal shows thorough understanding. Response is general and does not show how this will be applied.	
	(The greater the understanding, the better.)	Adv.: Considerably more.	Imp.: 20	Adv.:	Imp.:	Adv.: Slightly more understanding	Imp.: 5
	7.B Set-based design	Att.: Clearly fully understand and use the concept. Show how it would be applied.		Att.: Not sure that bidder has fully understanding.		Att.: Same comment as in 7.A.	
	(The greater the understanding, the better.)	Adv.: Considerably more understanding.	Imp.: 20	Adv.:	Imp.:	Adv.: Slightly more understanding	Imp.: 5
	7.C Target Value Design	Att.: Same comment as in 7.B.		Att.: Does not demonstrate a full understanding concept.		Att.: Same comment as in 7.A.	
	(The greater the understanding, the better.)	Adv.: Considerably more understanding.	Imp.: 20	Adv.:	Imp.:	Adv.: Slightly more understanding	Imp.: 5
	Total of As		**475**		**390**		**385**

Once the CBA example was finished, we define the weights (W) and the scale for WRC and BVS. In dependence of the BVS method, where the project team is selected by cost/quality point, price in WRC was assumed to be 50%. All other categories were estimated based on the points of the real case. For example, the category "A Quality Work & Learning Environment" was rated with a maximum of 1,500 points. Therefore, for WRC the weight is 12.5 % and for BVS 25.0% as price is not a weighted factor. Adapted from the available information, we establish the following rating: (0) doesn't meet minimum requirement, (1) meets requirement minimally, (2) meets requirement, (3) meets requirement good, (4) meets requirement very good, and (5) exceeds requirements. A bigger scale would be also possible, but therefore more information is necessary. Table 4 presents the evaluation using WRC and BVS.

Table 4: Constructed Case - Evaluation using WRC and BVS

Category	Rating (Scale 0-5)			WRC				BVS			
					Calculating				Calculating		
	B 1	B 2	B 3	W	B 1	B 2	B 3	W	B 1	B 2	B 3
Quality Work & Learning Environment	**3,50**	**3,00**	**2,50**	**0,125**	0,44	0,38	0,31	**0,25**	0,88	0,75	0,63
1.A Building interior program spaces	4	2	2								
1.B Workplace	4	3	2								
1.C Building interior	2	5	3								
1.D Daylight	4	2	3								
Model of Architectural & Urban Design	**3,33**	**3,00**	**3,00**	**0,125**	0,42	0,38	0,38	**0,25**	0,83	0,75	0,75
2.A Sight lines and passageways	3	3	4								
2.B Facade	3	4	4								
2.C Building interior: Workplace	4	2	1								
High Performing Building	**3,00**	**3,50**	**4,00**	**0,050**	0,15	0,18	0,20	**0,10**	0,30	0,35	0,40
3.A Light systems	2	2	5								
3.B Vegetated Roof	4	5	3								
Environmentally Sustainable	**2,00**	**1,00**	**2,50**	**0,050**	0,10	0,05	0,13	**0,10**	0,20	0,10	0,25
4.A Water saving	2	2	3								
4.B Materials	2	0	2								
Durable & long-lasting	**2,00**	**4,00**	**1,50**	**0,050**	0,10	0,20	0,08	**0,10**	0,20	0,40	0,15
5.A Vibration	2	4	2								
5.B Utilities system	2	4	1								
Efficiently Serviced & Maintained	**3,00**	**3,00**	**3,00**	**0,050**	0,15	0,15	0,15	**0,10**	0,30	0,30	0,30
6.A Faculty Workspace	4	2	3								
6.B Site lighting elements	2	4	3								
Quality & Clarity of Project Plan	**4,00**	**1,33**	**2,00**	**0,050**	0,20	0,07	0,10	**0,10**	0,40	0,13	0,20
7.A Last Planner^{TM}method	4	1	2								
7.B Set-based design	4	2	2								
7.C Target Value Design	4	1	2								
Price	**2**	**4**	**3**	**0,500**	1	2	1,5				
Total points					**2,554**	**3,392**	**2,838**		**3,108**	**2,783**	**2,675**
Price [in million $]									**93,8**	**92,5**	**93,7**
Cost/Quality point [in million $]									**30,177**	**33,324**	**35,028**

DISCUSSION

Figure 4 demonstrates the bidder ranking for each method. For our case in WRC the lowest bidder (bidder 2) would be selected. As the weight of the price proposal is 50 % in the case, price has a high impact on the ranking. With a high weight of the price factor the result does not differ from the lowest bid. However, by using BVS and CBA bidder 1 would be selected. Bidder 1 has a significantly higher score per price and is the best proposal. The difference in the value is visually better presented in using CBA. With a total score of 390 for bidder 2 and 385 for bidder 3 both teams have almost the same score, but they differ in the price. Bidder 2 is cheaper compared to bidder 3, but also compared to bidder 1. If total scores between two bidders are close, the public client could (if allowed by law) decide to choose the lower value with the lower bid price, if it presents the best value option. In WRC and BVS the bidder has to rank the calculated ratios. As a result, the score of the ratio is presented and will be compared. Cost ratio in BVS (if the project cost is not fixed) is not as clear as the CBA chart showing value vs. cost. In CBA we can clearly see that bidder 3 should not be selected because it provides a lower score than bidder 2, and it is more expensive. If using Target Value Design (TVD) the cost will be the same for all three bidders in CBA, and the analysis would be similar to BVS. However, the scores between BVS and CBA may differ even using the same information. Therefore, in the CBA example the only question is whether or not the owner is willing to pay 1.6 million more in order to obtain an 85 point higher score(importance of advantages). That decision is related to the available budget for the project, and not only to the cost/score ratio. The issue with the BVS ratio is that it may be an alternative that has a great cost/score ratio, but the cost may be over budget anyway unless the project cost is fixed in advance of the bid process. Moreover, in the BVS example developer herein it is not as easy to see which alternative is the one that provides more value. The BVS process of Mission Hall became a CBA-type process where the advantages are the determining factors and because the stipulated sum was written on to the bid form by the client the cost/score ratio was not in danger of providing a result where a lower-value project could win over a higher-value project. Hence, we state that the philosophy behind CBA is different compared to WRC and BVS.

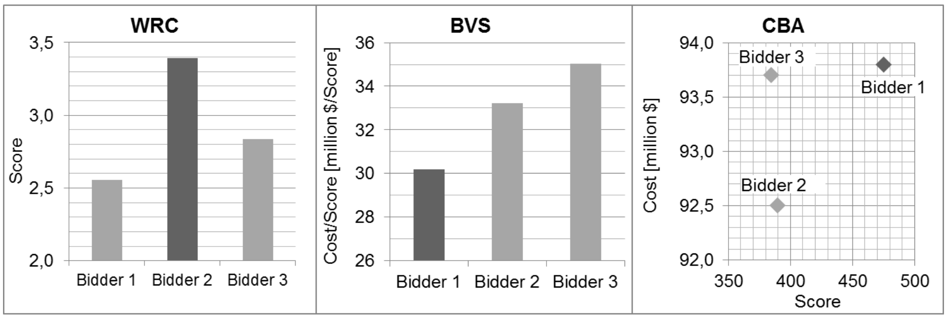

Figure 4: Overview of Results

In addition, using WRC and BVS are not as clear as documenting the rationale for the decision in transparent fashion as compared to CBA; because the attributes of the alternatives may not be as carefully summarized as in CBA. In other words in CBA one can more easily understand what attributes or characteristics of the alternatives are more valued by the owner. Besides, in CBA the criteria for selection also help decision-makers to agree on the differences between the bidders. On the other hand in WRC and BVS it is easier to assign scores, but without the more developed framework of CBA it is harder to explain what those scores mean. Consequently, it is important to mention that the difference in the score between bidders 2 and 3 is higher in CBA than when using BVS, because CBA only assigns scores to proposals which present an advantage in a factor, whereas in BVS and WRC every bidder receives a score for every factor.

For the public tendering procedures with complex decisions WRC is problematic as contrary factors are ignored. Another problem is the determination of the scoring scale and weights. Practically, the method is often implemented with insufficient data, resulting in misinterpretation. Factors are rated separately even when they depend upon each other. CBA includes the possibility that factors and criteria can be added at any time and a more important advantage than the paramount advantage can be added later. This possibility is problematic for the public tendering procedure. A public tendering process requires a stable framework, which does not change in a meaningful way as the proposal evolution process is carried out. Therefore, public owners need to establish procurement methods in advance; otherwise bidders can make claims against the tendering process, complicating or even nullifying the results, or forcing selection of a less-desirable alternative.

CONCLUSION

In this case study we can see that it is not a good idea to mix value with cost, as may be the case in WRC where the lowest bidder can use lower cost to overcome poorer value proposition compared with the other proposals. We recommend studying value separately from cost as in the case of BVS or CBA. BVS is an important improvement with regards to selecting the lowest bidder compared to WRC. However, we think that CBA provide additional benefits for helping public clients to differentiating between bidders. In CBA the value vs. cost relationship is showed in a chart, without assuming that a smaller cost/value ratio is better, allowing for a clearer perspective on value and cost. Furthermore, decisions are documented in greater detail; even when relative importance of advantages may be a subjective assessment, the relevant differences between the attributes of alternatives is highlighted.

Finally, we would like to comment on this study's limitations. The scoring behind the three methods may be biased by the researchers since we developed CBA first and then the scoring for WRC and BVS. Future research may provide a different setting for testing the three methods with different people using the three methods and trying to compare the level of conflict and consensus that the methods provide. Besides, for WRC a sensitivity analysis could be done to see how the weight of price factor impacts the bidder ranking. It also may be interesting to test the actual performance of the bidders after the decision is made with different methods.

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AN ANALYSIS OF POTENTIAL MISALIGNMENTS OF COMMERCIAL INCENTIVES IN INTEGRATED PROJECT DELIVERY AND TARGET VALUE DESIGN

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ABSTRACT

The misalignment of commercial incentives of a project delivery system can lead to client dissatisfaction, litigation, cost overruns, and adversarial relationships amongst project participants. Started in 2005, the goal of Integrated Project Delivery (IPD) is to better align the commercial incentives of project participants in the AEC industry. Started in 2004, the goal of Target Value Design (TVD) is to steer the design and construction of the project to maximize customer value within project constraints.

Recently, IPD and TVD have become more widely used in the United States' AEC industry. In this paper, we ask the following question: What are the misalignments of commercial incentives that can occur with IPD and TVD? We identified misalignments on 6 IPD/TVD projects. Additionally, we used a creative brainstorming exercise to propose possible misalignments, which were not reported in the case studies. For AEC practitioners and owners, understanding the potential misalignments may help them avoid these problems on their projects.

KEYWORDS

Target value design, integrated project delivery, relational contract, incentives

INTRODUCTION

The misalignment of commercial incentives within the AEC industry can lead to client dissatisfaction, low productivity, litigation, cost overruns, and adversarial relationships amongst project participant (Latham, 1994; Egan, 1998; Thomsen, et al., 2009). Several scholars and industry practitioners have cited misalignments of incentives of Design-Bid-Build (DBB) and CM at Risk (Thomsen, et al., 2009;

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Schöttle and Gehbauer, 2012). Design-Build (DB) attempts to overcome some of the misalignment problems of DBB and CM at Risk by having a single entity responsible for both the design and construction (Beard, 2003; Gransberg, Koch and Molennar, 2006). Even though DB has been cited to have less alignment issues than DBB and CM at Risk (Gransberg, Koch and Molennar, 2006), there are still reports of misalignment of commercial incentives with the DB project delivery system (Ling and Poh, 2007). Started in 2005, the goal of Integrated Project Delivery (IPD) is to better align the commercial incentives of project participants in the AEC industry (Matthews and Howell, 2005). Started in 2004, the practice of Target Value Design (TVD) steers the design and construction of the project to maximize customer value within project constraints (Ballard and Reiser, 2004; Ballard, 2011). Together IPD and TVD form a new project delivery system, which is often referred to as Lean Integrated Project Delivery (LIPD), IPD/TVD, or just Integrated Project Delivery (IPD). All three terms have been used synonymously by practitioners and scholars and for the purpose of this paper we will the term IPD/TVD to make a distinction that we are referring to projects in which both IPD and TVD are used together. Although TVD and IPD have often been used together (Denerolle, 2013; Ashcraft, 2010), not all TVD projects have used IPD principles and vice versa. In fact, the earliest TVD projects were undertaken under Design-Build GMP contract and the first IPD project made no mention of the practice of TVD (Ballard and Reiser, 2004; Matthews and Howell, 2005; Cohen, 2010).

Several scholars have reported that IPD/TVD is a better alignment of commercial incentives than more traditional project delivery systems (Lichtig, 2005; Thomsen, et al., 2009; Darrington and Lichtig, 2010). The successful results from IPD/TVD application have been attributed to collaboration and better alignment of incentives (Ziminia, Ballard and Pasquire, 2012). However, within the literature, there has been limited discussion about the misalignment of incentives with regards to IPD/TVD. Thomsen, et al. (2009) mentioned three misalignments of incentives: (1) members outside the risk pool may not be as incentivized to cooperative as members inside the risk pool, (2) IPD/TVD teams may pad their contingencies to increase their profit, and (3) there may be temptation from the IPD/TVD team to compromise quality and scope if the owner agrees to a fixed price early in design. Besides Thomsen, et al.'s (2009) report, we could not find any other scholarly article on the subject matter. The lack of reported knowledge on this topic may lead owners and AEC practitioners to believe that there are no problems with regards to misalignments of incentives with IPD/TVD.

In this paper, we play the role of a devil's advocate by asking the following question: "What are the misalignments of commercial incentives that can occur with IPD/TVD?" We interviewed 28 participants from 6 IPD/TVD projects to identify misalignments and problems that occurred as a result of them. We also used a creative brainstorming exercise to come up with possible misalignments, which have not been observed in the case studies. By understanding the potential pitfalls of IPD/TVD, owners and AEC practitioners may be able to avoid these problems on their own projects.While the term "alignment of commercial incentives" can be defined in many different ways, in this paper we will define it as: "actions by a project participant which benefits their firm financially would also benefit the owner, the project, and other participants". Under this definition, if a project participant's action benefits his or her firm financially but is detrimental to the team, the project, or the owner; then there is a misalignment of incentive. Having an alignment of commercial incentives is important in ensuring that everyone is working towards a common goal. We also acknowledge that while commercial incentives are important for a project, they are not the only type of incentives that exist. Participants undertake a project for a variety personal, social (e.g., recognition from winning a design award), and other types of incentives. And although the alignment of these incentives can be as important for a project's success as the commercial incentives, their discussion is beyond the scope of this paper. Our contribution to knowledge includes: (1) documenting examples of misalignments of incentives that occurred on IPD/TVD projects and (2) developing scenarios of possible misalignment of incentives. These empirical observations may help future scholars develop theories about IPD and TVD.

INTEGRATED PROJECT DELIVERY

The goal of IPD is to address four systemic problems of traditional contractual approaches: (1) good ideas are held back, (2) contracting limits the cooperation and innovation, (3) inability to coordinate, and (4) pressure for local optimization (Matthews and Howell, 2005). Under the motto of the three musketeers: "all for one and one for all", the original guiding principles for the IPD team were: (1) to have the IPD members responsible for the provisions of the prime contract with the client and (2) have the IPD members share in the risk and the profits of the project which is based on project performance (Matthews and Howell, 2005). Since its introduction in 2005, IPD has been gaining in popularly within the United States AEC industry with support from major organizations including the Lean Construction Institute, the American Institute of Architects, and the Associated General Contractors.

TARGET VALUE DESIGN

Target Value Design (TVD) is a management practice in which the design and construction is steered towards the project constraints while maximizing customer value (Ballard, 2011). TVD was adopted from Target Costing (TC), a management practicethat has been widely used in the new product development and manufacturing industries to ensure predictable profit planning (Cooper and Slagmulder, 1997; Feil, Yook and Kim, 2004). Under this approach, cost is view as an input in the design stage rather than an outcome of it.

PARTNERING AND PROJECT ALLIANCING

IPD/TVD is part of a larger, global movement towards more collaborative and relational contracting practices (Lahdenperä, 2012). Around the world, such practices as partnering and project alliancing are also gaining popularity (Abrahams and Cullen, 1998; Ross, 2003). The analysis of the misalignment of incentives of these project delivery systems is beyond the scope of this study. However, since project alliancing, partnering, and IPD share many common principles and practices, the findings from this research may help illuminate some of the misalignment of incentives of these project delivery systems as well.

RESEARCH METHODS

Eisenhardt (1989) defines a case study as "a research strategy that focuses on understanding the dynamics of single setting". According to Yin (2009), the case study method is appropriate when: asking "why" and "how" questions of contemporary phenomenon within real-life context where the researcher has little control in the experiment. As a relatively new project delivery system, the case study method allows us to collect in-depth data and insights of IPD/TVD. The case study method is especially appropriate for this research because our goal is to explore possibilities. One of the limitations of empirical research, especially the case study method, is that we can never be certain that we have observed all possible occurrences of a phenomenon. To overcome some of these limitations, we augmented our empirical research with theoretical investigation by brainstorming possible misalignments of incentives, which have not been observed in the cases.

CASE STUDIES SELECTION

This research is part of a larger 5-year research effort conducted by the University of California, Berkeley's Project Production Systems Laboratory (P2SL) in collaboration with our industry sponsors. For this research, we have collected data from 6 case study projects. The cases are within the Californian AEC industry. In total, the cases include (3) different owners, (3) different contractors, (4) different architects, (5) different structural engineering firms, and over a dozen different MEP trade partners. All 6 projects are with private owners and there were no regulatory restrictions with regards to procurement practices. The projects are all large-scale, complex projects ranging from $150 million to over $1 billion. Project C and Project E were the only projects in which there was a tri-party agreement between the owner, architect, and general contractor. On Project C and Project E, specialty contractors and designers held Lump Sum or GMP contracts with either the architect or the contractor. All of the other projects had between 7 and 13 parties in the risk pool. Projects D and F were joint ventures between 2 general contractors. Projects A, B, C, and E were all designed and constructed for the same owner (Owner 1). Projects D and F were designed and constructed for two different owners: Owner 2 and Owner 3 respectively. Having a wide variety of actors allows us to look at the problem with regards to misalignment of incentives from a systemic/industry perspective rather than just investigating problems from one firm or one particular project.

MISALIGNMENT OF COMMERCIAL INCENTIVES

MISALIGNMENT 1: IMBALANCE OF OVERHEAD AND PROFIT

Within an IPD/TVD project there are negotiated rates for: profit, contingency, and fees (i.e., cost of work[4] and overhead). The owner typically reimburses the IPD/TVD participants for their cost of work including a percentage markup to cover office overhead. The goal is to have the reimbursable rate equal to the firm's cost of running their business at 0 profit so that firms can only earn profit from the risk pool. When a

[4] The costs of work include material, equipment, salary, retirement, healthcare, and other benefits.

firm has a higher markup on their overhead than on their profit or when their reimbursable rate is greater than their cost of running their business, they can make more profit by billing additional hours to the project.

On Project E, the architect's negotiated fee (cost of work and overhead) was much higher than the fee that they normally charge on a similar project. For them spending more money meant that their company earned more profit at the expense of the team. By the end of the project, the architect had billed $2 million more than their initial estimates, which was taken out of the risk pool.

Table 1: Case Study Description

Project Labels	Description	Interviews
A	Hospital Project in Northern California	8
B	Hospital Project in Northern California	7
C	Medical Office Building in Northern California	3
D	Hospital Project in Southern California	6
E	Hospital Project in Northern California	2
F	Commercial Construction in Northern California	2

MISALIGNMENT 2:NOT ALL PROFITS ARE AT RISK.

On Project C, the IPD/TVD participants each placed 15% to 20% of their profits into the risk pool. Since the designers (engineers and architects) only had a small portion of the profit pool, they had limited upside from it. They did not truly have skin in the game and were not financially incentivized to go the extra mile to pursue cost saving designs that benefitted the whole project.

MISALIGNMENT 3:DIFFICULTY OF BUDGET AND SCOPE TO MOVE BETWEEN CLUSTER GROUPS.

On several projects, the cost savings from one cluster group through the TVD process was held tightly within that particular cluster. The cluster group with the savings kept it within their group as a contingency and hoarded the money instead of allowing it to move across boundaries. On Project E, the design team held a sizeable design contingency even after the sustainable amount to the design was already completed. They knew that they would not need to use it but were reluctant to let the funds free. At the same time, another cluster group was over budget and had to make less than optimal compromises to hit their Target Costs. This resulted in a non-optimal allocation of capital that could have been invested for value added scope or to allow other clusters to meet their targets.

MISALIGNMENT 4:PAYMENT BY REIMBURSABLE DOES NOT REFLECT THE PROGRESS OF THE PROJECT.

On Project A and Project B, the IPD/TVD team did not share their labor productivity rates with each other. From the owner's perspective, there was no way for them to compare the billing rate with the rate of installation to make sure that contractors were on schedule. From the team's perspective, they were relying on the word of their partners and did not have data to verify the statements. On Project A, one trade partner inside the risk pool ended up depleting a sizeable portion of the profits. Since the team was not actively tracking and sharing labor rates (i.e., projected vs. actual man-hours), the issue was not revealed until near the end of the project at which point there was little that could be done to ameliorate the problem.

MISALIGNMENT 5: UNTIMELY DISPERSION OF PROFITS.

On Project C, a participant remarked that the profits were not dispersed in a timely manner. The project had already been completed for close to 3 months but the final profits were not released to the team. Because there is a time value to money, owners may want to keep the money for as long as possible in order to earn an interest on it. Untimely dispersion of profits can also make it difficult for AEC companies to manage their cash flow.

MISALIGNMENT 6:MEMBERS THAT HAVE A MAJOR IMPACT ON THE PROJECT'S SCHEDULE AND COST WERE NOT IN THE RISK POOL.

On Project B, a member outside the risk pool had a scope of work that was critical to the success of the project. By not having this subcontractor inside the risk pool, the IPD/TVD had little influence over their actions. The subcontractor did not attend the big room meetings and it was difficult to communicate/coordinate with them. And as a result of this and several other issues, the project ended up behind schedule and over budget. Members who are outside of the risk pool may be motivated to work in a manner that is most efficient for them but not efficient for the project. This local optimization comes at the expense of the team's profitability and the project's outcome.

MISALIGNMENT 7: MEMBERS OUTSIDE THE RISK POOL DID NOT ATTEND COORDINATION MEETINGS.

On several projects, some members outside the risk pool did not attend the coordination meetings. The designers and subcontractors outside the risk pool were procured under either a Lump Sum or GMP contract and their estimates reflected a more traditional project delivery system where they were "in and out" without much interaction with other parties. Within their estimates, they did not budget enough money for attending the big room meeting. For these parties, each coordination meeting that they attend reduces their profits and is a lost opportunity for making profit on another project.

MISALIGNMENT 8: THE TARGET COST WAS SET BASED ON PRICE RATHER THAN WORTH AND IS NOT SHARED WITH THE TEAM.

On several of the case study projects, participants have reported that the Target Cost was handed to them by the owner rather than developed as a team. Some of the IPD/TVD participants did not know how the Target Cost and the Target program was set. The fact that the team was not involved in the development of a Target Cost and did not validate it base on the owner's business case meant that the Target Cost might have been was set based on price rather than worth. It may be tempting for owners to ratchet the Target Cost from project to project without consideration of whether or not the Target Cost is actually achievable. In doing so, projects may be undertaken which are destined to fail because there was never an alignment between the ends, means, and constraints.

MISALIGNMENT 9:OWNERS WHO WANT THE BENEFITS OF TVD/IPD BUT WERE NOT WILLING TO DO THE WORK.

Project F involved an owner who does not engage in construction projects on a regular basis. The owner wanted to try IPD/TVD on their projects because they heard about the benefits of the process. However, the owner was not actively involved in many of the decision-making sessions. After an extensive amount of the design was already completed, the owner wanted to make several changes that were costly and difficult to integrated into the existing plans.

MISALIGNMENT 10:OWNERS FORCING THE TEAM TO CUT THEIR PROFITS.

The IPD/TVD contract is typically signed after a sustainable amount of the design has already been completed. This usually occurred either during the Design Documentation (DD) or the Construction Documentation (CD) stage. Prior to signing the IPD/TVD contract, the designers and contractors are typically paid by a GMP design-assist contract. By the time the IPD/TVD contract is ready to be signed, the IPD/TVD team had already invested a significant amount of effort, energy, and prided into the project. It is in the team's best interest to move the project into the construction phase. The contractor and trade partners typically spend more upfront money in the preconstruction phase than they are compensated for. As a result, they can only recouped their investments if they also participate in the construction phase.

Due to a downturn in the economy, several projects in the case study sample had owners who recalculated their Target Cost to reflect the change in the economy. From the owner organization's perspective, they can get a better deal by putting the project up for bid in the market. In order to remain on the project, the IPD/TVD team had to lower their negotiated fees, profits, and contingency percentages on these projects. This action had a profoundly negative impact on the team's morale and eroded trust between the team and the owner.

Table 2: Observed Misalignments of Commercial Incentives

Labels	A	B	C	D	E	F
M1	X	X			X	
M2					X	
M3	X		X		X	X
M4	X	X				
M5			X			
M6		X				
M7	X	X		X	X	
M8		X				X
M9						X
M10		X			X	

CREATIVE BRAINSTORMING EXCERCISE

In this section, we list some of the misalignments of commercial incentives that were not observed on the case study projects but may be possible with IPD/TVD.

MISALIGNMENT 11:CONTINGENCY DOES NOT TRULY REFLECT THE RISK INVOLVED AND MAY BE HIDDEN ELSEWHERE.

IPD/TVD projects typically have a contingency percentage that is significantly lower than the industry average (Do, et al., 2014). In the construction industry, some owners and IPD/TVD teams are "setting" the construction contingency at 0 percent (Ashcraft, 2014). The logic behind this is that since the people who designed the project are also the ones who are going to build it, they should not need any contingency. Unfortunately, uncertainty is a natural part of every complex system and prudent TVD/IPD team members will always have a contingency. Some members may try to hide this contingency by padding their estimates and while others may simply not include any contingency in their estimates. Both practices can become recipes for disaster. The first encourages deceptive behaviors that are contrary to the principles of IPD. The second results in greater financial risks for the participants.

MISALIGNMENT 12:EXPLOITATION BY OWNERS TO GET A PROJECT WITHOUT PAYING AEC PRACTITIONERS A PROFIT.

By setting a Target Cost at a rate that is unachievable, the owner may try to exploit the relational contract to pay the AEC professionals for their cost of work and 0 profit.

MISALIGNMENT 13:MEMBERS SIGNING ONTO AN IPD/TVD PROJECT WITH NO INTENTIONS OF ACHIEVING THE TARGET COST.

Contractors or designers may, in difficult financial times, join an IPD/TVD project with no intentions of hitting the Target Cost. For these firms, the IPD/TVD project is a temporary shelter for them to "park" some of their people and equipment since they are guaranteed their cost of work. Unfortunately, having an underperforming team member can hurt the morale of the IPD/TVD team. This problem is compounded if the IPD/TVD member is making "profit" from an imbalance of overhead and profit.

MISALIGNMENT 14:FIRMS DO NOT SEND THEIR BEST PEOPLE TO WORK ON TVD/IPD PROJECTS.

Some owners may set the profits percentage of an IPD/TVD project to be less than a more traditional project delivery systems due to a lower perceived risk of the project for AEC practitioners. In order to maximize profits, firms logically send their best people to work on projects where they can make the most money. If there is less upside with IPD/TVD, firms may not send their best people to work on them.

MISALIGNMENT 15: THERE IS A LACK OF COMPETITION SINCE THE CONSTRUCTION IS NOT COMPETITIVELY BID OUT.

One of the concerns that owners have with IPD/TVD is that since the construction phase is not competitively bid, how can owners know that they are getting the best price. On all of the 6 case studies, the owners used a variant of the best value selection process to select firms based on qualification and price. On Project D, the owner started the project with a design competition.

DISCUSSION

Many of the misalignments of incentives can be avoided if owners and IPD/TVD participants: (1) select only trusted and capable members, (2) educate each other about their business models and key performance metrics, (3) take the time to learn how IPD/TVD is different than more traditional project delivery systems, (4) make sure that everyone has adequate training in Lean Construction, and (5) have adequate resources for IPD/TVD. The IPD/TVD process makes the AEC practitioners more vulnerable to unscrupulous partners and owners. Likewise, owners can also be vulnerable to a bad IPD/TVD team. As a result, this project delivery system should only be used with trusted and capable partners.

In conclusion, the problems relating to the misalignment of incentives is not limited to one discipline or on one project. They were observed on all of the case study projects. Owners, architects, engineers, contractors, and trade partners are all susceptible to temptations and local optimization. The goal of this paper was to highlight some of the misalignments of commercial incentives within IPD/TVD so that owners and AEC practitioners can be aware of them and have a proactive strategy for them. IPD/TVD projects have been completed with exceptional quality, cost, and schedule results (Seed, 2014); however, there is still room for improvement. Armed with the knowledge from this paper, owners and AEC practitioners can improve their IPD/TVD implementation, leading to more successful project outcomes.

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PROJECT MANAGER OR PROJECT LEADER: WHAT IT TAKES TO CREATE A HIGH PERFORMING

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ABSTRACT

This case study compares two projects that achieved success with integrated lean project delivery (ILPD). The frameworks are William Seed's new project manager theory, Bass's transformational leadership model, and Kotter's manager vs. leader. This study answered these RQs: 1.What are the personality traits, strengths, and leadership styles of the ILPD Project Managers? 2. Did the IPMs change their leadership style and behavior during the project lifecycle? 3. How does the behavior of the IPMs change over the life of a project? The desire for early team involvement in the design and development efforts and strong multidisciplinary collaboration demands a high performing team environment, which requires a new kind of leader. These teams delivered multi-million dollar hospital building projects under budget and ahead of schedule. Through interviewing the project managers and analyzing their StrengthFinder2.0 and DiSC Personality Assessments, this case study shows that the key to success in these particular teams was (a) team members' understanding of communication skills, (b) a mix of leadership strengths and personality traits, and (c) technical knowledge of experienced project managers [PMs]. Limitations of the study and its findings are discussed at length.

KEYWORDS

High performing team, integrated project delivery, project manager, leadership, DiSC

INTRODUCTION

Two teams were studied, which will be referred to as the east coast (EC) project team and the west coast (WC) project team, within the United States. To gain additional insight into what traits define an integrated project manager (IPM), the researchers used the DiSC personality profile and StrengthsFinder 2.0 assessments to determine if there are any traits or strengths that stand out in each team, as well as collectively across both teams. In addition, both teams were interviewed to examine if their leadership and communication skills transformed.

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As organizations begin to move away from the traditional design-bid-build method of delivery and toward the integrated project delivery method of lean construction, the mentality, leadership ability, and communication aptitudes must be adjusted and perfected. The purpose of this study is to observe whether the two separate IPD teams' project managers have similar strengths and behavioral tendencies that enabled them to meet their conditions of satisfaction under budget and ahead of schedule.

WEST COAST AND EAST COAST IPD PROJECT OVERVIEW

Both teams were assembled through a value-based proposal and interview process that sought to identify potential team members with the following attributes: innovation ability, target value design knowledge, willingness to learn, team strength (skills and abilities), and team chemistry (individual fit with balance of team). Table 1 depicts partnership structure, project description targets, and outcomes. The teams were assembled before design began.

Table 1. Project Size and Scope Comparison

	West coast	**East coast**
Type of facility	Surgical hospital	Psychiatric bed additions; outpatient offices
Facility offerings	144 beds, 6 operating suites, diagnostic imaging, full service care	80 inpatient adolescent Psychiatric beds and treatment areas
Size of new construction	200,000 square feet, 500-car parking, 37 acres	21,000 square feet, 100-car parking, 5 acres
Years concept to completion	3.5 (5 - 7 year market average) 20 days early	1.16 (1.5 - 2 year market average)
Anticipated and real profit and costs	150%, target = $144 MM(40% below market), final = $144 MM, $2 MM bonus	150%, target = $9.9 MM (12% below market), final = $9.75 MM, $256 K bonus
$ Savings	18 MM design, 7 MM construction	700 K design, 750 K construction
Challenges	Off-site road work	30-day site permit delay

RESEARCH QUESTIONS

This study answered these RQs: 1.What are the personality traits, strengths, and leadership styles of the ILPD Project Managers? 2. Did the IPMs change their leadership style and behavior during the project lifecycle? 3. How does their behavior of the IPMs change over the life of a project?

LITERATURE REVIEW

THE BURNING PLATFORM FOR LEADERSHIP IN THE IPD WORLD

IPD, as defined by the American Institute of Architects, is “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 optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all the phases of design, fabrication, construction, and occupancy” (Duke, Higgs, and McMahon, 2010, p.9). With a variety of jobs and players coordinating efforts, project managers now see their contractor as their trade partner.

Seed (2014, p.3) states that “the early involvement of constructors and specialty trades, and strong multi-disciplinary collaboration with designers, demands a new kind of leadership”. There are many viewpoints on the definition of leadership, as well as the key competencies of leadership. Kotter (1996, p.29) defines the key role of managers as to “plan and budget, organize and staff, and control and solve problems, whereas leaders establish direction, align people, and motivate and inspire”. The role of manager still applies to the IPM, but now the IPM is expected to lead different stakeholders across multiple entities to ensure that, as a team they meet their conditions of satisfaction.

The project manager that pushes hard on the supply chain participants to perform—without their input or concern for their needs—would be less effective within IPD. Pushing can be compared to Maxwell’s Level 1 Leadership (authority based on a job title), as well as Goleman’s (2000, p.82) coercive leadership style, which he describes as “demands immediate compliance”, which can be seen as contrary to lean principles. Zenger and Folkman’s (2009, p.12) research indicates that there are five competencies of leadership (focus on results, personal capability, interpersonal skills, leading organizational change, and character) that primarily revolve around the character competency.

Project managers in lean construction must move away from a solely transactional leadership style to embrace transformational leadership. To understand the differences, Avolio and Bass’s (2004) transactional leadership model consists of contingent reward and management by exception (active), while Avolio and Bass’s (2004) transformational leadership model consists of the following traits: charisma, inspirational motivation, intellectual stimulation, individualized consideration.

While individual leadership in the IPD world is very important, group leadership is key. Rath and Conchie (2008, pp.22-23) found from their strengths research that “while each member had his or her own unique strengths, the most cohesive and successful teams possessed a broader grouping of strengths,” and found that they consisted of “executing, influencing, relationship building, and strategic thinking”. The concept of group leadership with IPD can be considered crucial because of the many disciplines that are involved in designing and constructing a building and the “win as a team” mentality. Rath and Conchie (2008, pp.23-24) go on to state that “Although individuals need not be well-rounded, teams should be” and that “a tool like StrengthsFinder can be useful in determining how all team members can maximize their contribution to the group's collective goals".

COMMUNICATION AND EMOTIONAL INTELLIGENCE

Goleman (2000, p.80) defines Emotional Intelligence [EI] as follows: "the ability to manage ourselves and our relationships effectively consists of four fundamental capabilities: self-awareness, self-management, social awareness, and social skill". Patterson, et al. (2012, pp.9-10) state that "20 years of research involving more than 100,000 people reveals that the key skill of effective leaders, teammates, parents, and loved ones is the capacity to skillfully address emotionally and politically risky issues". With IPD being a relatively new concept and not a widely accepted process (thus potentially political and emotionally risky); it is necessary for project managers to be able to communicate at an extremely high level to be able to change the mind-sets adhering to the typical design-bid-build delivery model. The IPM must be able to inspire others to think in terms of total value stream versus local optimization.

When dealing with others, Goleman (2000, p.80) defines one of the core competencies of social awareness as the skill of sensing other people's emotions, understanding their perspective, and taking an active interest in their concerns. Having the "proficiency at cultivating and maintaining a web of relationships" competency is crucial, because trade partners and design partners are now challenging themselves to work together to develop long term cost effective sustainable designs, reverse the erosion of labor productivity, improve the safety conditions, increase profit, and deliver optimum value to the final customer.

METHOD

The researchers chose the case study method because it presents an in-depth understanding of the case and understanding of several individuals' common or shared experiences (Creswell, 2013). The researchers chose to use the DiSC personality test, StrengthsFinder 2.0 Assessment, and author-designed open-ended interview questions to obtain in-depth answers on how the IPMs grew professionally over the course of their respective projects.

Having seen a number successful projects, and observing in these two cases a unique project team environment, the authors chose these two teams to determine if there is something that could be identified and replicated on future projects. The participants were chosen by the authors based upon a prior professional relationship and must be considered a convenience sample and also a purposive sample. These projects had resulted in a high level of success relative to their size and scope. Five main project leaders from each team participated, for a total of 10 participants. Both teams were able to finish their projects ahead of schedule and under budget, as well as maximizing the customer's conditions of satisfaction (see Table 1). Because of their group success, the authors chose a qualitative approach to acquire a deeper understanding how team chemistry and personality traits may have resulted in project success.

The researchers chose to use the DiSC behavioural assessment because it measures behavioral style rather than beliefs or attitudes. Sugerman (2009, p.152) states that "The key to a successful relationship lies with a person's ability to identify what interpersonal style he or she prefers, and how to engage others whose own DiSC styles may be quite different".

The researchers examined whether there was a common behavioral style within both of these teams. According to TTI Success Insights (2014), the DiSC Assessment measures how one habitually does the following: responds to problems and challenges (D), influences others to one's point of view (I), responds to the pace of the environment (S), and responds to rules and procedures set by others (C). The DiSC assessment measures each participant's natural style of dealing with how they "respond to stress and the pressure to adapt to the environment" (TTI Success Insights, 2014, p. 11). Next, the researchers chose to measure whether the participants had similar talents and strengths in common, and used the well-known tool, StrengthsFinder 2.0. Further, the researchers conducted interviews via email with each of the project manager participants and asked them to reflect on (a) how their leadership and communication styles changed (or not) throughout the duration of their IPD project, and (b) what they remember as the defining moments that helped make the project succeed.

The DiSC Personality Test taken by all 10 participants is considered to have acceptable internal consistency (reliability) by achieving a Cronbach's α minimum of 0.826 and have been validated by external sources(TTI Success Insights, 2014). For SF 2.0, Gallup found by using Cronbach's α, that the StrengthsFinder 2.0 "has previously found test-retest reliabilities of 0.60-0.80 for the 180-item version of the CSF" (Asplund, et al., 2007, p.14). Based on Cronbach's α, both assessments are valid to describe strengths and behavioral style. As a human subjects concern, "There is no evidence to suggest any of the TTI assessments (DiSC) could cause adverse impact with regard to gender, race, disability or veteran status" (p. 2).

RESULTS

The table shows select participants' StrengthsFinder 2.0 and DiSC results, as well as each teams' results at the two lowest rows of each team's results. Core Clarity (2014) provided the results reports for both teams. For the WC team, activator was the top strength. This characteristic is defined by Rath (2007, p.41) as being "impatient for action" and as a mindset that "analysis has its uses or that debate and discussion can occasionally yield some valuable insights, but deep down you know that only action is real". For the EC team, the top strengths were responsibility and individualization, which demonstrates that collectively, they have the ability to depend on each other and appreciate the rest of their teammates for what they bring to the table. Another top theme is relator, which indicates that they get along well with teammates. From the S.F. 2.0. assessment, both teams are more naturally willing to work as a team while maintaining their dedication to getting the tasks done. The Integrated Form of Agreement (IFOA) environment allows them to think beyond the individual role or company affiliation to better the project. While there was diversity among the IPMs on each team, there was also consistency of focus on task management. The ability to maximize the individual talents while surrounded by individuals with complementary strengths in a trusting relationship helped focus the teams toward continuous improvement. The combination of responsibility and relator seemed to support each other. The relator characteristic reinforces amiability within the team, and the ability to count on each other reinforces the relationships. These traits may have allowed the other unique traits to come to bear when needed, due to the trust formed. The researchers grouped the top two highest scoring behaviors. The DiSC Results table shows there are significant differences and similarities between the two teams. As an example of differences, the WC team's top workplace behaviors are urgency and versatility.

Table 2. StrengthsFinder 2.0 Results (Strongest on Left to Weaker on Right)

West Coast Results					
Mech. Des.	Adapt.	Ideation	Strategic	Connect.	Relator
GC 1	Relator	Ideation	Futuristic	Activator	Self-Assur.
GC 2	Activator	Futuristic	Strategic	Command	Relator
Electr.	achiever	competition	Restorat.	Response.	Harmony
Architect	Response.	Command	Commun.	Activator	Achiever
Comb.	Activator	*Relator*	Ideation	Futuristic	*Response.*
Strength	Eager	Friend	Creative	Visionary	Depend.
East Coast Results					
Owner	Ideation	Relator	arranger	learner	Intellection
Mech. Des.	Achiever	Learner	Relator	Maximize	Response.
GC 1	Harmony	Individual.	Response.	Consist.	Belief
GC 2	Activator	Individual.	Strategic	Respon.	Futuristic
Architect	Discipline	Analytical	Deliber.	Harmony	Focus
Comb.	Response.	Individual.	Harmony	Relator	Learner
Strength	Depend.	Discerning	Mediator	Friend	Curious

Note. Italic indicates shared traits between the East Coast and West Coast teams.

Target Training International (TTI) defines versatility as "bringing together a multitude of talents and a willingness to adapt the talents to changing assignments as required" and urgency as "decisiveness, quick response, and fast action," which could help them mobilize quickly to overcome organizational bureaucracy and any other constraints that could prevent them from reaching their conditions for satisfaction. Next, the EC team's top workplace behaviors were an organized workplace and analysis of data, which qualifies them as a team that strives for a well-defined process and is data-driven. TTI describes the organized workplace behavioral style as "systems and procedures followed for success" and the analysis of data as "information is maintained accurately for repeated examination as required." These results are matched by one of the authors' firsthand observations. As an example of a major similarity: frequent interaction with others was high for both teams, which TTI describes as "dealing with multiple interruptions on a continual basis, always maintaining a friendly interface with others." After closer examination, the participants who scored 9.0 or above on the frequent interaction with others behavioral category scored above 50 points in their adapted style and natural style for the influencing category. TTI reports that these participants' natural style is to use persuasion and emotion to the extreme. They are positive and seek to win by the virtues of personality and verbal skills, displaying enthusiasm for projects.

Table 3. DiSC Results

WC Team	Adapted style				Natural style			
Role in project	**Dom.**	**Infl.**	**Stead**	**Com.**	**Dom.**	**Infl.**	**Stea.**	**Com.**
Mechan. PM	66 Frequent interaction (9.0)	93 Frequent change (9.0)	14	6	78	94	34	6
Sr. Superinten.	41 Frequent interaction (7.0)	68 Competitiveness (7.0)	45	58	63	65	63	26
GC PM	93 Urgency (10.0)	65 Compet. (10.0)	12	26	100	66	7	35
Electr.PM	66 Organized workplace (9.5)	22 Analysis of data (9.5)	37	79	68	16	56	74
Sr.Arch.	62 Urgency (8.0)	74 Versatility (8.0)	24	58	68	68	14	38
Team M	66	64	26	45	75	62	35	36
Team Mdn	66	68	24	58	68	66	34	35

EC Team	Adapted style				Natural style			
Role in project	Dom.	Infl.	Stead	Com.	Dom.	Infl.	Stea.	Com.
GC PM	63 Organized workplace (8.5)	32 Analysis of data (8.5)	38	77	68	28	58	61
Mechan. PM	16 Follow-up and follow thru (10.0)	22 Following policy (10.0)	74	92	18	26	84	84
Sr. Estim.	43 Frequent interactions (9.0)	93 Versatility (9.0)	14	32	62	93	22	28
Owner PM	58 Follow-up follow thru (8.3)	38 Following policy (7.8)	65	56	62	28	68	55
Sr. Architect	64 Organized workplace (9.5)	8 Analysis of data (9.5)	24	93	66	24	14	91
Team M	49	39	43	70	55	40	49	64
Team Mdn	58	32	38	77	62	28	58	61
Both teams combined M	57	52	35	58	65	51	42	50
Both teams combined Mdn	63	52	31	58	67	47	45	47

Note. Styles: dom. = dominance, inf. = influencing, stea. = steadiness, com. = compliance, compet. = competitiveness; parentheses indicate participant's top workplace behavioral score.

Only one person scored above 90 for the dominance category; TTI states that such a score indicates that a participant "tends to deal with problems and challenges in a demanding, driving, and self-willed manner. He or she is individualistic in his or her approach and actively seeks goals." The participant with the lowest score in the dominance category is described as being "cautious in approach to problem solving and does not attempt to demand that his or her view or opinion be accepted at face value. He or she likes to solve problems within the framework of a team environment and will look for a compromise as opposed to a win-lose situation."

For the steadiness behavioral category, the highest score was 84 for natural, and 74 for adapted. TTI describes this participant He or she "prefers to complete one task before starting the next and prefers an environment that is predictable." The lowest score in this category was 12, indicating one who is “comfortable in an environment that is constantly changing. Even when the environment is frantic, he or she can still maintain a sense of equilibrium.

For the compliance behavioral category, the highest score was a 93 for adapted and 91 for natural style. TTI states that this participant “is concerned with doing things right. He or she will follow rules and procedures to the letter and feels comfortable in a situation in which exact standards and written procedures are the rule of the day.” The lowest compliance score is 6 for both natural and adapted styles. Such a person “does not like constraints; at times he or she can be somewhat defiant and rebellious”.

INTERVIEW RESULTS

Participants were given Likert-scale and open-ended questions and all results were submitted in writing. Three concepts emerged as universally and strongly agreed on. First, while commanding is the more traditional leadership style for project managers, the ability to understand and use these [team-oriented] leadership traits frees an individual or the team as a whole to innovate. Second, a sense of shared pressure and responsibility rather than individual pressure, or a confidence in the team members that relieves some pressure, frees the team to innovate. Third, trust and vulnerability allow people to say “I don’t know” and ask for help, which drives better outcomes, specifically with designer/builder interactions.

Participants were then asked: “During the course of your IPD project, did you exhibit or learn how to use any of these leadership styles: commanding, visionary, affiliative, democratic, pacesetting, coaching (Goleman’s six leadership styles); charisma, inspiration, intellectual stimulation, individualized consideration (Bass’s transformational leadership characteristics); or transform from one style to another?” The top response overall was a use of visionary. To ensure that all of the participants had a grasp on the theories, the authors encouraged questions for clarification, and gave clarification upon request.

Participants were asked a follow up question as to which of these styles, if any, they were aspiring to. The top two answers were visionary and coaching. For this question, another that the WC team participants rated highly was charisma. For the EC team, coaching was more highly rated, then democratic and charisma. One participant stated, “ILPD projects dictate that you become a coach, inspire others…Traditional project delivery methods lend themselves much more to a command and control style of leadership, mainly in my opinion because you're starting from a contractual position of distrust versus trust.” Another participant commented, “I feel that I need to add more of the coaching leadership style to my overall leadership style...helping others learn to be better leaders in an effort to build a bigger leadership pool. This is both internal to our organization and within project teams.” One participant stated, “I think that we were successful because I allowed the field leaders an opportunity to think freely without the threat of retribution. This fostered an environment of collaboration and innovation that would occur in a normal situation,” while another participant stated, “While I understood, as a manager of my staff and co-workers, the need to incorporate these competencies [EI] into the management of people, the IPD process helped me to appreciate the effect and benefit.” One participant stated, “I definitely got better at social awareness and especially empathy. Because of the dynamics of the project I was able to see how other people worked and how things affected them.” A change of leadership mind-set took place for participants, due to an IPD process that requires an IPM who expresses empathy with trade partners.

Participants were asked: During the course of your IPD project, did you develop any of Goleman’s EI competencies that had not been used in a traditional project delivery? Across both teams, the vast majority strongly agreed with the team mentality principle for their IPD projects, and they had to use different leadership styles to accomplish the project as a team. One of the top three themes that emerged from the interviews was that while commanding is the more traditional leadership style, the ability to understand and use other leadership traits frees an individual or the team as a whole to innovate. Similar comments included: “Put myself in the owner or user shoes more often.” “Was able to work towards the right path for the project, rather than for my company.” “My typical style starts with ‘pacesetting’ and then trends towards ‘democratic’ as trust is built.” Common themes that emerged for leadership style were affiliative and visionary across both teams. Empathy was the most common emotional intelligence trait developed.

CONCLUSION

This case study offered an inside view of how successful project leaders perceived that they were able to harness their combined personality traits, strengths, leadership, and communication skills to successfully complete IPD projects. The DiSC results showed that no one behavioral style was common across each team; the median ranged between 24 to 68 (out of 100) for both teams. There were very high scores (90s) and very low scores (under 10), which shows that both teams had a diverse set of behavioral characteristics. There is not an IPM “alpha trait” shared in these two teams. For the StrengthsFinder 2.0 results, the EC team’s top strength was responsibility (naturally dependable), whereas the WC team’s top strength was activator (naturally eager). The results show that both teams had responsibility and relator (natural friend) in their top five strengths, meaning that, according to Core Clarity (2014, p.7), both teams are “devoted to enhancing existing connections, risking intimacy to build trust and loyalty,” while at the same time include the virtue that “promised results occur with virtually no supervision”. Both teams exhibited the ability to “purposefully forge deep, genuine, mutually beneficial, and ultimately long-lasting relationships”. The top leadership styles that the participants noted overall were visionary and coaching (Goleman, 2000). Participants noted it is more difficult to apply pressure to a trade partner than a traditional subcontractor, which indicates the IPM must be empathetic towards the needs of their team members to reach a joint goal, and not use a primarily directive style. The main take-home message is that in a team environment, no one behavioral style is necessarily better than another, but when they are combined successfully, the end result can be optimized outcomes.

A limitation of this study is that it only examines a small sliver of the IPD projects that are currently underway in the world. It would be advantageous to use different tools, such as the Belbin and Myers-Briggs assessments. Lastly, it would be beneficial to interview the followers of the leaders under study to truly understand the impact on the project from their perspective.

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A DEEPER LOOK INTO THE PERCEPTION AND DISPOSITION TO INTEGRATED PROJECT DELIVERY (IPD) IN COLOMBIA

Sebastian Forero[1], SebastianCardenas[2], Hernando Vargas[3], and Camilo Garcia[4]

ABSTRACT

Integrated Project Delivery (IPD) has been utilized as an alternative project delivery method by encouraging team collaboration, sharing risks/rewards, and more importantly, requiring trust and transparency amongst all stakeholders for projects in the United States. In Colombia, a traditional approach for delivery of projects is typically utilized under a Design/Bid/Build model with limited collaboration. This paper describes the analysis conducted to evaluate potential barriers of implementation of IPD concepts as a delivery method for construction projects in Colombia. The analysis conducted includes research of perceived cultural, financial, legal and technological barriers to stimulate the adoption of collaborative delivery models. It includes a survey and interviews with different stakeholders and industry members (developers, designers, construction managers and general contractors) to understand the benefits and shortcomings when engaging with collaborative methods. Survey results were evaluated by using correlational coefficient models to gauge dependencies among all factors identified as potential inhibitors of IPD. Detailed analyses of the findings as well as future steps for a successful implementation of IPD in Latin America, focused in the Colombian case study are discussed.

KEYWORDS

Integrated project delivery (IPD), Colombia, South America, implementation barriers, collaboration, project management, trust, transparency, design/bid/build

INTRODUCTION

With the coming of age of innovative delivery methods, an in depth analysis of the potential barriers of implementation of Integrated Project Delivery (IPD) concepts as

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a successful methods for delivering projects in South America needs to be analyzed. It can be easily pointed out, that in the Colombian market constructability processes, contract administration and project management are closely linked to fear of change and lack of innovation, obstructing significant and necessary advancements on the development of this industry. One of the main reasons for the reduced implementation, is the lack of knowledge about new methods, poor communication about the risk/rewards of each option, and ultimately little existence of transparency and trust amongst the different stakeholders, where individual goals triumph instead of group goals.

LITERATURE REVIEW

Construction (Project) Management originates as the industry response to the problems of complexity and productivity that the construction industry was experiencing a few years back. In the 1960's in the United States began to shape the idea of establishing the concept of Construction Management as a solution to the inefficiency and capacity problems for large projects originated by the traditional "Design-Bid-Build". Model. Later came the model of "Design-Build" consisting in awarding the design and construction processes to a single entity, giving security improvements for the client on costs and time objectives. Simultaneously to this model, in Australia began the use of "Project Alliancing"[5] (Sakal, 2005) through collaboration, team work and group goals, looking forward to the project development. This approach showed excellent results in each one of the projects were it was implemented, launching the solution and arriving to the United States where it was called Integrated Project Delivery or IPD.

The American Institute of Architects (A.I.A.) defines IPD[6] (AIA, 2007) as a focus of Project execution integrating people, systems, business structure and practices inside a process that collaboratively takes advantage of talents and ideas of all the involved, reducing waste and increasing the efficiency through the design, fabrication and construction stages. This methodology not only claims to improve cost and time results, but also foster individual work of all involved parts, where the traditional idea of searching an individual goal is left behind and it is replaced with objectives and guidelines focused in a common goal, the project profit and the value creation for the involved stakeholders. A.I.A. proposes as key principles: trust and mutual respect, shared risk and reward, collaborative innovation and decision making, early involvement of the key participants, early definition of the goals, intensified planning, open communication, organization and leadership and multiparty agreements. [7] (Kent and Becerik-Gerber, 2010)

IPD is closely linked with project information sharing and its availability for any of the team members. At this point technology plays a primary role assisting

[5] Project Alliancing: A Relational Contracting Mechanism for Dynamic Projects. Lean Construction Journal 2005, vol 2, p 70. (2005). Sakal, Matthew W.

[6] Definition presented in Integrated Project Delivery: A Guide, Version 1 (2007). The American Institute of Architects.

[7] Understanding Construction Industry Experience and Attitudes toward Integrated Project Delivery. Journal of Construction Engineering and Management, Vol. 136, No. 8, pp. 815-825. (2010).Kent and Becerik-Gerber.

inefficient and intelligent means of communication. Building Information Modeling (BIM) is one of the main components required when executing an IPD project to ensure the Team can visualize the project early on and through detail model coordination.

Results obtained with IPD reflect significant progress for the industry, with estimated savings of 30% [8] (UKOGC, 2007) of construction cost by promoting stakeholders team work and profit. For project owners, IPD not only allows them to play a vital role participating and contributing with their ideas and opinions in the execution stages but also significant savings in costs and times. For contractors, having an integrated execution process allows them to build a project out of alternative studies to the client satisfaction creating and innovating by the use of the latest technologies and improving financial results, understanding from the beginning each stakeholder expectation, accomplishing and sometimes overcoming their needs. For designers, it means reduction of unnecessary work and information availability, having the opportunity to learn side by side with contractors performing quality job without the necessity of revisions, leaving behind problems of misinterpretations or incomplete information.

HYPOTHESES

To evaluate the main implementation barriers of IPD in Colombia, we developed an array of hypotheses to gain a better understanding of the limitations of such novel approach and its potential implementation.

- *Old School Mentality*: Fear of change, where management models stay away from innovation with little interest to new tendencies. Passive thought that considers that what has been working for several years still works today.
- *Transparency*: One sided contracts, with no transparency and equality on the distributed risk. Contracts with preferences and inconsistencies that favor a few and seek individual profit instead of group profit.
- *Silo Approach*: Professional specialization with sectored tasks and procedures segregating construction processes. Lack of team work thinking, searching for individual goals prevailing over group goals. Unsupportive culture where the progress and learning are not shared or transmitted to others.
- *Limit the End Goal*: Restrictions in resource allocation for work execution and developing of new ideas. Buildings and projects developed in the limit where is only achieved the minimum required for obtain profits and decrease the expenses. Lack of economic and knowledge resources to implement new technologies as Building Information Modeling.
- *Commitments*: Absence of control over project deadlines, lacking stakeholders' commitment.

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[8] Achieving excellence in construction procurement guide, Vol. 5 at pag.6 (2007). The United Kingdom's Office of Government Commerce (UKOGC). www.ogc.gov.uk

RESEARCH METHODOLOGY

SURVEY

A survey was completed to analyze the hypothesis presented above, and gain a grass root understanding of the potential limitations of this undertaking. The survey was targeted to key individuals and groups of stakeholders having an impact in the Colombian construction industry. The study was composed of fifty-two (52) questions divided into four main categories. Categories applicable for this survey were: 1. General/Introduction, 2. IPD Specific Questions., 3. Building Information Modeling (BIM) and 4. Lean (Last Planner) questions. The intent was to not only question respondents about IPD knowledge but also to gauge their understanding of their forward thinking mechanism for innovative topics such as BIM and Lean. The survey was sent to a total of 139 participants, representing: Clients/Owners (8 responses), Constructors (26 responses), Designers/Consultants/Architects (9responses), and Project Managers (5 responses) for a total of 48 respondents (35% response rate).

RESULTS

As a follow up to the survey, interviews were conducted with four (4) key participants to gain a better in depth understanding of their answers. The results are presented next to challenge the hypotheses presented previously. An in-depth numeric as well as statistics analysis was conducted to the responses received. Results were classified by group or sector to which each respondent belonged, and the most significant and relevant questions were chosen to be consolidated in graphs as presented below.

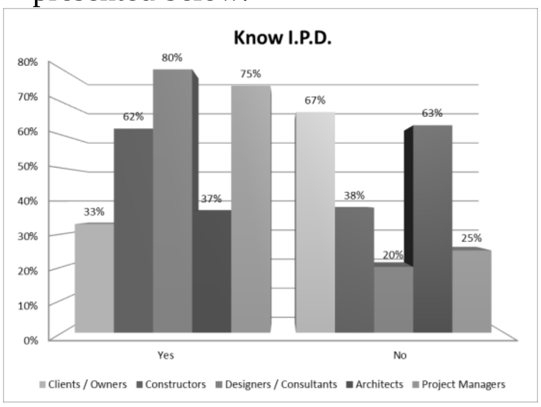

Figure 1: Number of Respondents Knowing IPD by Sectors

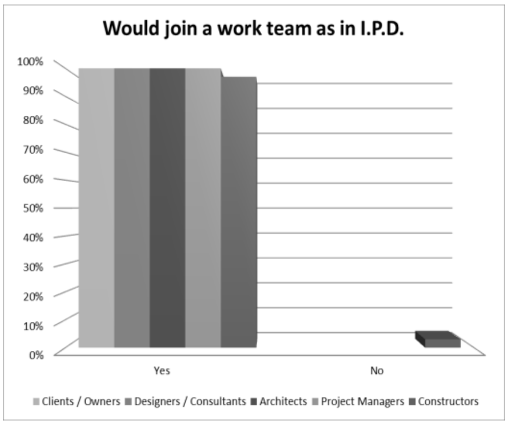

Figure 2: Number of Respondents that would join a Work Team as in IPD

One of the main concepts proposed by IPD is the creation of a team composed of the general contractor, designer and client/owner. The readiness of the companies for this idea is vital for its possible implementation. A 98% (Figure 2) of the participants would be interested in joining a team like this.

There are countless problems in the different stages of the execution of a construction project. In early stages of coordination it is crucial to set main goals and objectives. The obvious first question was to inquire the group about their beliefs on the main causes for not meeting established design milestones in a project. The responses obtained (Figure 3) are as follows, and suggest an interesting trend around lack of communication and poor commitments (not meeting deadlines) as the biggest obstacle.

In the Colombian construction industry, project management and delivery occurs in a traditional way, not focusing on innovation and development. It can be easily stated, that during the last few years the majority of the construction processes has unfortunately not evolved at all. For this reason, we wanted to understand this barrier and limitation to outline an innovative process (Figure 4).

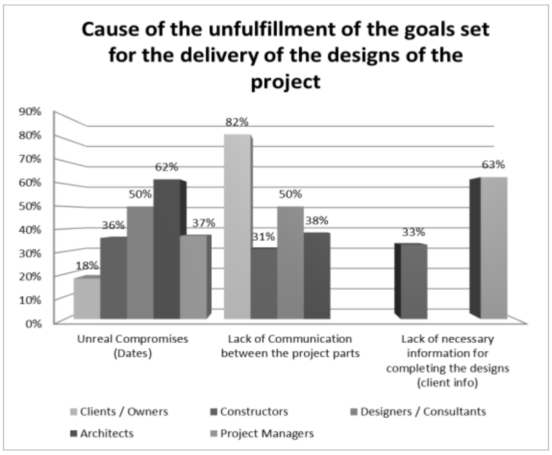

Figure 3: Causes of not Meeting Goals for Project's Design Delivery Milestones

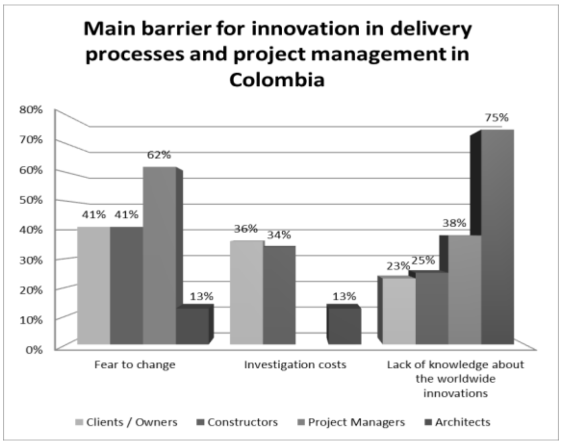

Figure 4: Main Barriers for Innovation in Delivery Processes and Project Management in Colombia

Another concept presented by IPD is the Multi-party agreements. It was important to understand the type of stakeholders that would be willing to take part and execute projects following this approach. Based in this question (Figure 5) it was found that the majority of stakeholders (83%) would sign it. This is an overwhelming majority. The main reason for the balance of the respondents (17%) to not join a multi-party agreement are factors such as fear, lack of knowledge, distrust or simply disinterest on IPD.

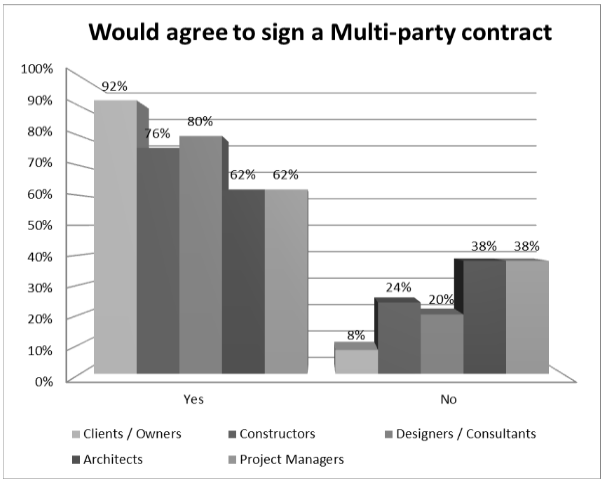

Figure 5: Number of Respondents that would

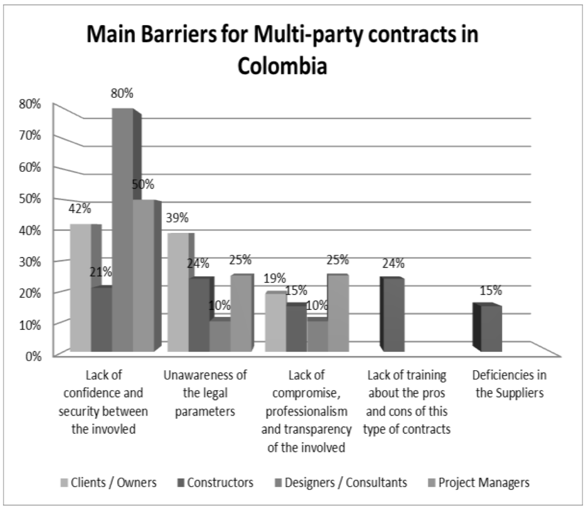

Figure 6: Main Barriers for Multi-party

Sign a Multi-party Contract *Contracts in Colombia*

Based on the answer presented before, we wanted to dig deeper and understand the main barriers to implement an IPD method (Figure 6). Interesting answers obtained are presented below, reinforcing the point that lack of confidence (trust) is the main barrier of implementation.

In most cases, contractors work and their early involvement in integrated teamwork are undervalued, producing problems of non-fulfilment and overruns. 93% of the respondents answered positively, representing the big interest of the industry for this to happen.

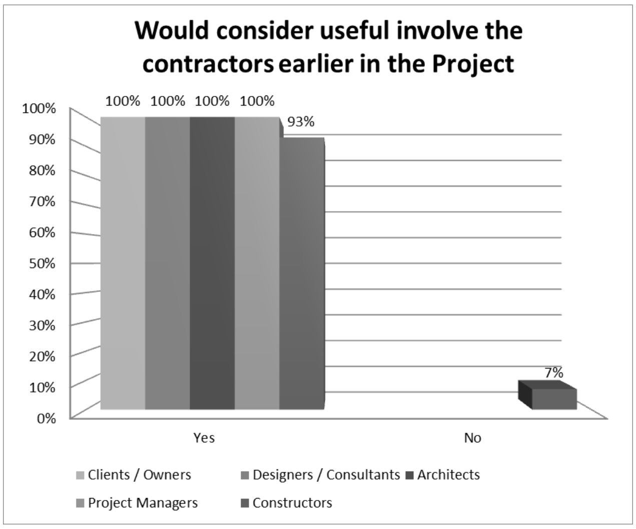

Figure 7: Number of Respondents that would consider Useful to involve Contractors Earlier in the Project

Some tools and concepts implemented in IPD have gained more acceptance and recognition than the doctrine itself. This is the case of Building Information Modeling and Lean Construction – Last Planner. This situation can be evidenced due the efforts of companies for evolve and innovate inside a very conservative industry, searching for a better planning, organization and quality between the stakeholders. A high percentage (66%) know BIM, and standing out the respondents from big (>200 employees) and medium (between 51 and 200 employees) companies (Figure 8).

One of the main worries and likewise interest of the industry is to obtain more efficient results using more ordered mechanisms and more completed planning, recognizing activities and objectives that are pretended to achieve, reducing the uncertainty and imprecision in each stage of the project. With this in mind arise the need to know the level of knowledge about methodologies as Lean Construction – Last Planner; 64% of the respondents did know the concept (Figure 9), being very similar than the results for BIM. These results suggest that the concepts of BIM and Lean are more popular than IPD and multiparty contacts.

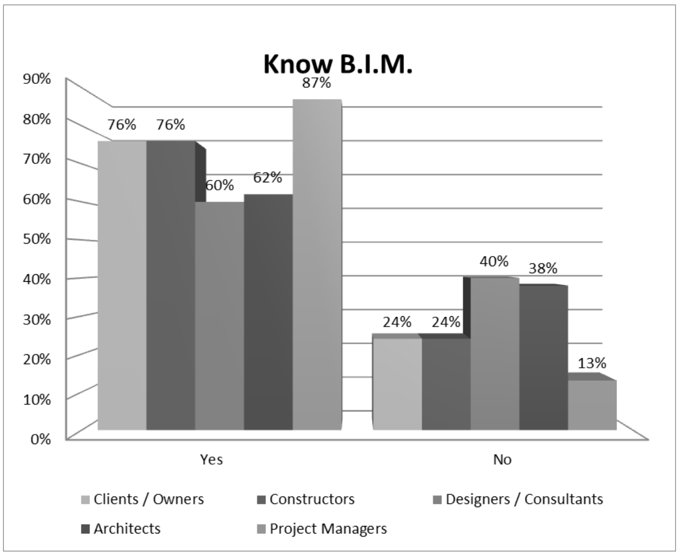

Figure 8: Number of Respondents that Know BIM

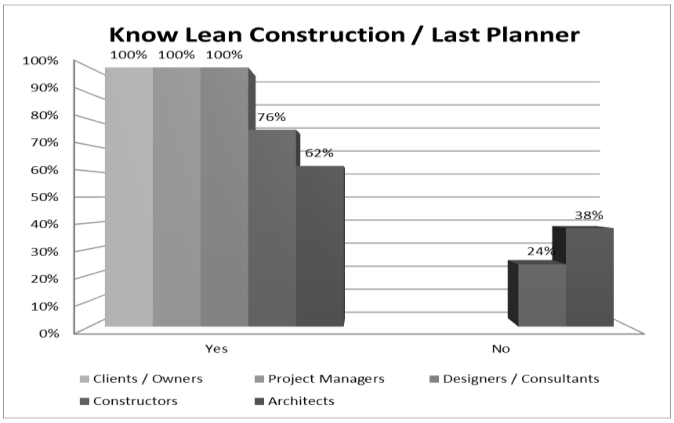

Figure 9: Number of Respondents that Know Lean Construction

RESULTS ANALYSIS

Fear to change was considered one of the main barriers for IPD implementation in Colombia. Results denied this hypothesis and ratified the interest of a great majority of the stakeholders for the progress and development of the construction industry. Every respondent is aware of the pitfalls and problems of the industry and agreed in the need of mechanism that can guarantee more effective results.

The hypothesis of poor valuation of the transparency in contracts, methodologies and administrative processes is confirmed. There are groups very interested in the transparency and equality in contracts. Is important to mention that there are still stakeholders opposing the open and transparent methodologies, considering it as unnecessary or dangerous. The constant fear and distrust between the involved parties minimizes the spirit of these ideas resulting in mechanisms of “hyper control” that obstruct a dynamic and efficient work.

Precarious communication between the key stakeholders of the Project makes the process of delivery a simple task of great complexity. According to the results the thought about team work exists but only inside each company. Thinking of a holistic approach with team that works between different companies becomes less attractive.

The group objectives of the companies engaged on a project such as satisfaction of the client, decrease in overruns, reduce the waste of materials and minimize delays, become secondary to economic remuneration and personal growth. The lack of organization and deficient planning are the principal cause of the most harmful problems for the correct execution of projects.

In the Colombian construction industry there is an environment where initial costs and low budget mentality prevail over the quality of the work. The hope is to maximize the profits with lowest possible investment affecting quality and generating risks. It is uncommon to allocate company resources to study and adopt new methodologies and technology because of the intangible results. The use of new technologies such as BIM, Last Planner, etc. is very limited. The required technological advancement and infrastructure tools exist and are available, but the proper training interest from the companies to invest on this upfront cost, is almost impossible to obtain.

The lack of compromise between stakeholders is evident and the ultimate goal of greater profits as the sole source of success it is an element that has nothing to do with the final result of other key parameters of the project. Quality and client satisfaction are not even considered as measures of success.

Concepts as the Big Room, multi-party agreements, shared profits, etc. as proposed by the IPD (Constructor, Designer and Client), present a good reception from the stakeholders. Results show that the 70% of the respondents would work with the method or consider its implementation appropriate. This encourages the implementation of IPD in emerging markets as the Colombian promising a lot of benefits for the industry.

A follow up statistical analysis using correlations intended to quantify and identify possible relationships between some specific questions of the surveys was conducted.

First it was sought to identify whether there is any relationship between knowledge and familiarity of the concept of Integrated Project Delivery (IPD) with the perception that there are more effective ways to design/build a project where all interdisciplinary teams work together from the early stages of the project. Based on responses from surveys and statistical analysis in STATA, it can be concluded that General Contractors and Developers have a negative correlation towards this two issues. However, for designers, there is a high correlation between understanding the concept of IPD and the perception that there are better ways to execute the project.

As far as open book approach and sharing of budget information, we found that general contractors have very low dependence between the willingness to report in detail all the costs to the project team, and willingness to work on a project in which the budget is set by the team at the initial stages of the project. This indicates that although builders are possibly willing to report their costs, they would be unwilling to work with a fixed budget since early stages.

Regarding multi-party contracts, we analyzed the dependence that each of the companies was willing to sign a multiparty contract with the possibility of distributing the project profit according to the performance of each of the parties involved. The statistical results show that General Contractors and Construction Managers have a high correlation between these two variables, indicating that these actors consider that the multiparty contract can promote or contribute to the transparency required for each party to accept to put all the project utility in the same bag and distribute it based on performance and participation of each of the parties involved. However, designers and developers have a very low or any correlation on this issue, which may indicate ignorance about what a multi-party contract is, or that they simply do not agree with this methodology.

Finally, it was found that constructors, project managers, and developers have a high dependency or correlation between familiarity or knowledge of the concepts of BIM and Lean - Last Planner, while designers presented a zero correlation with these concepts. This means that designers are not familiar at all with concepts such as BIM and Lean.

CONCLUSIONS & RECOMMENDATIONS

Construction industry in emergent markets tends to be very traditional, but that does not mean that they are not ready to adapt and change. The willingness of the companies to develop and engage with new tendencies is one of the principal advantages to bring forth and adopt new ideas that have given excellent results abroad. It is necessary to recognize the usefulness of creating clusters in early stages among stakeholders. All innovation and change awakes rejection, but in this particular case and based on the analysis of the survey, there is definitely interest to engage this novel approach. The need to transform the industry is evident.

The main objectives and goals in order to succeed, need to be focus on aligning the industry towards a transparent, integrated and inclusive approach that seeks to minimize the overruns, waste and break the silos down. It is key to develop this approach, to link education with industry, where mutual collaboration is achieved, generating development and progress. IPD can be implemented in Colombia. Physical, economical and cognitive resources for the development of this methodology and its correct implementation inside the local companies are available.

The main barriers defined and established with this study are the lack of knowledge and information about the topic representing an easy obstacle by opening the doors to continue the study, investigation and promotion of this field, along with people and companies training on this approach. Asymmetry between designers and contractors is evident, demanding to focus around an inclusive industry future, recognizing each group perception of the value that one and another can add to the project in pro of the optimization of the project execution and reinforce the permanent communication bridges between the main involved from the beginning to the end of the project. There is no need to fear to change the way of thinking towards a new way of doing things in a different and more efficient way, and becomes a vital necessity to be able to apply all the theoretical knowledge in real results in the practice.

There are many activities to follow, label IPD under a Spanish name that bear the concepts of integrated work that it promotes. It will be necessary to stimulate local companies to study IPD implementation, using practical cases from other countries, the benefits of an implementation of the IPD and compare the results with a Project developed with a traditional construction method. Apply to a national study Project, the concept of a team or society formed by the owner, constructor and designer, documenting possible problems and advantages of this methodology.

Promote the use of new technologies and methodologies as Lean Construction, BIM, Big Room, Multi-party agreements, etc. being trained about these and applying them into case studies that evidence the results obtained with each one. Design and standardize multi-party agreements of easy use and implementation from the contractual basis of each country. Study a particular case where the contractors be involved in early stages of the Project and compare the results in terms of costs and times with a case where the contractors are involved belatedly. Do a practical exercise of a Big Room where constructors, designers and clients are invited, simulating a fictitious Project that have to develop during certain period of time inside this space and where fundamental decisions are made for each of the stages of the execution of the Project, and finally distribute the fictitious profits according to the performance of each group; document the results and the participants opinions. Assuming that early adopters will be the private sector, and once it has shown its benefits mimic in the public sector.

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COST MANAGEMENT

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A CRITICAL REVIEW OF THE SAFEGUARDING PROBLEM IN CONSTRUCTION PROCUREMENT: UNPICKING THE COHERENT CURRENT MODEL

Christine Pasquire[1], Saad Sarhan[2], and Andrew King[3]

ABSTRACT

The construction industry has, over a long period, been criticised for its short term "hit-and-run" relationships which are focused on win-lose situations and poor performance. Despite the wide recognition of these problems the industry persistently resists the radical demanded of it. This paper attempts to investigate why this might be the case by reviewing prevailing safeguarding practices within the current commercial systems and structures through literature review and industry observation.

Findings reveal that clients and decision makers often tend to safeguard their project-specific assets, against opportunism and exploitation, through the deployment of formal contractual arrangements and governance structures. These arrangements and structures typically dominate the management of the project delivery often to the detriment of the project itself; but because there is a belief that interests are safeguarded, clients and decision makers feel they have taken the best course of action. This goes a long way to explaining the coherence of the current construction model and provides the basic information for preparing a route to the radical change required to move to lean methodologies.

KEYWORDS:

Waste, Procurement, Contracts, Opportunism, Transaction Cost Economics.

INTRODUCTION

During his presentation at the IGLC 20 Industry Day in San Diego in 2012, Gregory Howell then the president of LCI, referred to the prevailing construction approach as

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a "very coherent model" when explaining the barriers to lean implementation. Yet the performance of the industry has been widely criticised, often regarded as confrontational, risk averse, and lacking trust and capacity for innovation and improvement (Zaghloul and Hartman, 2003; Eriksson and Laan, 2007; Eriksson, Nilsson and Atkin, 2008). Why therefore is the model so coherent and so embedded? This paper uses Transaction Cost Economics to explain the current inertia focusing particularly on the idea of self-interest (or safe-guarding) and how this is a source of waste hitherto unacknowledged.

Waste in construction originally addressed physical waste but the discussion widened with the introduction of the "lean" process waste. Both of these types of waste can be directly associated with production. In this we can say that production is about doing work of some sort and that this includes the production of design information and specification. This understanding of waste encourages the improvement of current processes rather than radical new system design. Does this go part way to explain why Liker (2004) observe many lean implementations stalling and not achieving their full potential? A wider examination and conception of waste is needed and one aspect of this is the consideration of the organisational, commercial and institutional environments that surround the design and delivery of construction projects. The foundation for understanding waste begins with defining value which in turn enables non-value to be identified. Traditionally waste (non-value) has been identified as anything that consumes resources but adds no value – the constituents of value have similarly been widely discussed but again mostly from within the design and delivery processes. It is clear that some non-value is essential and that much of this is in the logistical and supporting structures surrounding project delivery. The understanding of value and non-value (waste) within the wider organisational, commercial and institutional environments is more difficult to conceptualise not least because it requires a critical evaluation of the activities of different professions (e.g. lawyers, accountants, human resource managers, quantity surveyors and so on) and varying organisational cultures/structures/systems/behaviours.

This evaluation also has to draw upon theory from disciplines outside both construction and manufacturing such as economics, law and sociology, if we explain the phenomenon of coherence within the current construction project delivery approach. The current approach contains many inefficiencies that have been frequently attributed to factors such as industry fragmentation (Egan, 1998) adversarial hierarchy structure of projects (Ghassemi and Becerik-Gerber, 2011), obsolete procurement methods (Eriksson and Laan, 2007), confusing and treacherous contractual arrangements (Hawkins, 2012; Cox, and Thompson, 1997), the highly competitive cost-driven environment (Bresnen and Marshall, 2000) and the sequential organisation of construction processes (Koskela, 2000). Due to the transient and discrete nature of many of the construction projects, clients and decision makers, in practice, tend to recognise these as risks and seek to protect their project-specific investments and assets, from exploitation and opportunism, through the deployment of formal contractual arrangements and governance mechanisms. Since, most clients who procure construction projects lack experience and may only ever build once or twice (Love, Davis, Ellis, and Cheung, 2010); they invariably seek advice from lawyers and from those who are familiar with construction contracts and the laws related to them (e.g. quantity surveyors). These lawyers or consultants would accordingly be paid, as part of their agreed fees, for providing means for safeguarding their client's rights and transaction-specific assets. Unsurprisingly, in some cases these means can, for example, include the use of privileged conditions of contract, where clients may not mind protecting themselves from any risks, even if, this occurs at the expense of others and ultimately themselves. For instance, the inappropriate risk allocation in the use of disclaimer (exculpatory) clauses which can attract between 8% - 20% of the total project cost as contingency (Zaghloul and Hartman 2003). In this case, a contingency that clearly consumes resource without adding practical value and thus conforms to the archetypal definition of waste. However, in most cases, clients' main intentions are to control opportunism and utilise efficient governance of their transactions. But, arguably, they may not be aware of how their procurement decisions and arrangements may affect the likelihood of creating a cooperative environment (Eriksson, Nilsson and Atkin, 2008) and thus impact project performance and outcomes. According to Williamson (2000) "Any issue that arises as or can be reformulated as a contracting issue can be examined to advantage in transaction cost economising terms" (p599, 608). Thus, transaction cost economics (TCE) seems to provide insights into why current practice seems to be coherent by explaining a model focused on managing contracts rather than managing production.

TRANSACTION COST ECONOMICS

It is Coase's seminal article "The Nature of the Firm" (1937) which explicitly introduced the concept of transaction costs into economic analysis; and drew to our attention that there are transaction costs that had been assumed to be zero in prior theorizing. Transaction costs are the costs of specifying what is being exchanged and of enforcing the consequent agreements (i.e. contractual clauses) against the exchange partner (North, 1994; Ting, Chen, and Bartholomew, 2007). Its focus is on the transaction or "doing the deal" rather than "doing the work" and is typified by the frequent complaint from a variety of practitioners that re-tendering sub-contract packages in order to reduce cost usually causes costly knock-on problems. By riding roughshod over relationships the constant drive to reduce cost often has the opposite effect, causing margin slippage and increasing the likelihood of costly dispute as all parties seek to safeguard their financial position. Williamson (1975) categorises transaction costs into ex-ante and ex-post costs. Ex-ante costs comprise the costs of tendering, negotiating and writing the contract (Rindfleisch and Heide, 1997); while ex-post costs include the costs of: monitoring and measuring performance, implementing quality control systems, cost accounting, establishing layers of the managerial hierarchy, and dispute resolution processes (Rindfleisch and Heide, 1997).

The TCE framework is underpinned by the interaction between two fundamental assumptions of human behaviour (i.e. opportunism and bounded rationality) and two key dimensions of transactions (i.e. asset specificity and uncertainty). There is also a third behavioural assumption of risk neutrality and a third transactional dimension of transaction frequency or relational exchange (Williamson, 1985). In this opportunism as "*self-interest seeking with guile*" (Williamson, 1985, p. 47) implying that given the opportunity, decision makers may deceitfully seek to serve their self-interests. Muris (1981, p. 521, cited in Ting, Chen, and Bartholomew, 2007) adds to this and argues that opportunism arises when a party "*behaves contrary to the other party's understanding of their contract, but not necessarily contrary to the agreement's* *explicit terms, leading to a transfer of wealth from one party to the other*." In reality, opportunistic behaviours are part of human nature, and therefore they often exist in exchange-relationships (Ting, Chen, and Bartholomew, 2007). However, it can be argued that although opportunism may, initially, lead to increased outcomes for the opportunistic party, it actually has the potential to restrict value creation and decrease revenues for both parties in a relationship, that is because considerable amounts of resources would then have to be spent on enforcing, monitoring and controlling functions instead of employing those resources for other productive purposes (Ting, Chen, and Bartholomew, 2007). Bounded rationality simply means that decision makers act rationally but have constraints on their cognitive, analytical and data-processing capabilities, especially in uncertain and complex environments (Rindfleisch and Heide, 1997). According to Dietrich (1994: 19), the concept of 'bounded rationality' in transactions is based on two principles. First, that there are limits on a human's ability to process information without error. Secondly, that it is not wise to suggest that past experience can help in every situation encountered. Asset specificity refers to investments (transaction specific assets) that have a 'lock-in effect' (Ting, Chen, and Bartholomew, 2007) because they make it difficult to terminate a relationship and select other parties without acquiring losses. Uncertainty can be defined in its simplest form as what is known in comparison to what needs to be known. During transactions (ex-ante and ex-post contractual stages), two types of uncertainty are encountered: behavioural and environmental transaction uncertainty. TCE conceptualises 'behavioural uncertainty' as the amount of difficulty associated with monitoring and evaluating the performance of the exchange partners against established contractual agreements; while 'environmental uncertainty' is theorised as unanticipated changes in circumstances and the associated complexity surrounding the transaction context (Williamson, 1985).

In short, TC theory assumes that the greater the transaction uncertainty and asset specificity and the lower the transaction frequency, the higher the transaction costs (Bradach and Eccles, 1989). This understanding underpins much of the accepted procurement theory and practice taught in Universities and recommended by professional institutions. It also suggests that exchange cannot be fully specified ex ante, and that contractual performance cannot be easily verified ex post, due to bounded rationality and uncertainty factors (Rindfleisch and Heide, 1997). Having provided an explanation to the theory's constructs and main assumptions; next we discuss the consequences of the interplay that occurs between these constructs, which in turn lead to a number of governance challenges.

THE SAFEGUARDING PROBLEM AND THE GOVERNANCE MECHANISM

A '*safeguarding problem'* arises when a firm deploys transaction-specific assets and worries that its exchange-partner may opportunistically try to exploit these unique investments (Rindfleisch and Heide, 1997). Accordingly, it can be concluded that asset specificity and opportunism are the antecedents of the safeguarding problem. Figure 1 represents a simplified graphical representation of the governance problems and possible solutions. According to Rindfleisch and Heide (1997), the basic premise of TC analysis is that if those three governance problems described above are absent or low, decision-makers will accordingly favour market governance to vertical integration (the make-or-buy decision). Alternatively, if the transaction costs required for overcoming the governance problems exceed the production cost advantages of the market, firms will favour internal organization (Coase, 1937). Williamson (1985) has augmented this conventional approach to transaction economising and introduced the concept of 'relational contracting' as a more positive and sustaining form of governance which solves governance problems through behavioural norms rather than potential sanctions (Ting, Chen, and Bartholomew, 2007).

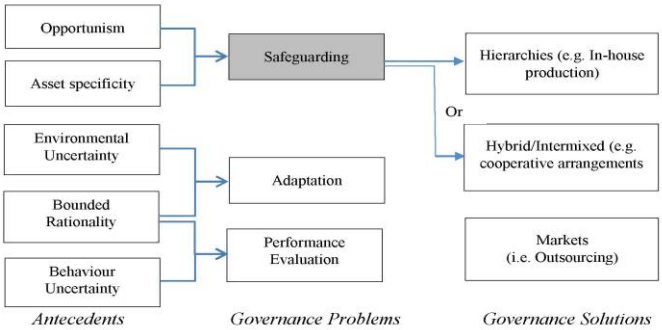

Figure 1: A basic model of transactional governance problems and solutions

In essence, TCE has the objective of total cost minimisation (Rindfleisch and Heide, 1997) and assumes that transactions will be governed by the institutional arrangements that are most efficient (Bradach and Eccles, 1989). This implies that, according to TCE, the institutional arrangement chosen will be that which reduces the total costs (transactional or organizational costs plus production costs) of undertaking and coordinating those activities. Similarly, clients when deploying their procurement arrangements in general, and safeguarding techniques and approaches in specific, should therefore put into consideration the impact of their decisions on project-team's performance and total costs. The situation in construction however does not confirm to this explanation as the numerous one-off construction clients and their decision makers attempt to implement a *"buy-it"* transaction in a "*make-it"* environment where a team comes together for a specific purpose (to deliver the project). The consistent failure of this approach to perform has created increasingly draconian and wasteful activity in order to safeguard parties from the failures. There are many safeguarding approaches used in construction procurement and these include the use of disclaimer clauses; conventional insurance arrangements; collateral warranties; performance bonds and cash retentions; lump sum pricing strategies. The discussion of imperfect safeguarding approaches used in construction must start with an examination of standard forms of contact.

STANDARD FORMS OF CONTRACT - AN IMPERFECT SAFEGUARDING APPROACH IN CONSTRUCTION

Construction parties rely heavily on contract formalisation through the use of standard forms of contracts (Eriksson and Laan, 2007). Theoretically, standard forms of contract optimise the balance of risk and responsibility between the parties, and eliminate ex-ante transactional costs required for re-drafting and getting familiar with new contracts (Cox and Thompson, 1997). Their main advantage is that they enable a body of experience in their use to be developed among the whole industry (Williamson, Wilson, Skitmore, and Runeson, 2004). This includes the formation of an established body of case law which can assist in the drafting and interpretation of contracts (Laryea and Hughes, 2009). Thus, as a safeguarding technique, they are supposed to reduce the amount of time and risk involved for contract administrators and tenderers as well.

However, there are many problems related to the use of standard forms of contract. These forms of contract are drafted by third parties who focused their formulation of the contracts on specific types of projects; thus one of the main problems associated with the use of un-amended standard forms of contract is their inability to adapt to the context in which they operate (Laryea and Hughes, 2009). Nevertheless, in practice, clients rarely use standard-form contracts without making some amendments to them (Laryea and Hughes, 2009), and the same applies to subcontracts. A study by Laryea and Hughes (2009) which was based on four observational case studies in two of the top contracting companies in the UK, showed that these amendments made by clients are mostly related to payment issues and legal arrangements. Similarly, an exploratory study of 11 Swedish construction projects, by Osipova and Erksson (2011), reported that in all 11 projects, clients made amendments to the general conditions of contract to transfer more risks to the contractor; many of them were applied to the length of guarantee and additional insurance. Laryea and Hughes (2009) revealed that a general perception exists among contractors that clients amend conditions of standard contracts and introduce their own special clauses, in order to gain an advantage rather than genuinely to suit the project needs. Additionally, Hawkins (2012) warns that users making amendments to standard forms of contract at negotiation stages do not always ensure that all the interlinked clauses affected by the amendments are also amended leading to ambiguities and encouraging opportunistic behaviour. Additionally, a study by Love *et al.* (2010) identified onerous and one sided amendments to standard forms, often drafted by lawyers to improve their clients' position, as one of the underlying dynamic factors influencing disputes.

At the same time, it is important to emphasise that lawyers and specialist surveyors are not the primary users of a contract (Sarhan, Pasquire, and King, 2014); it is the project parties' ability to capture their meaning which is fundamental for contract performance (Rameezdeen and Rodrigo, 2013). In general, textual complexity of standard forms of contract, in terms of readability and comprehensiveness, may lead to misinterpretation and lack of common understanding between project parties; thus supporting arms' length relationships and potential time-consuming and costly disputes (Rameezdeen and Rajapakse, 2007). Additionally, one of the major critiques concerning the adoption of standard form of contracts is associated with the dominance of adversarial dispute resolution mechanisms within many of these contracts (Mante, Ndekugri, Ankrah, and Hammond, 2012). Furthermore, the availability of adjudication clauses as contained in standard forms of contract make disputes a less disruptive action for the parties concerned (Love, Davis, Ellis, and Cheung, 2010); thereby hindering collaboration efforts.

In summary, it seems that the problems of standard forms of contract outweigh its advantages. The heavy reliance on the use of standard forms of contract, established by third parties, brings with it lots of formality and rigidity that stifles cooperation and focusses on the individual parties and their responsibilities; thereby driving a distance between project parties and encouraging opportunistic behaviour (Eriksson, Nilsson and Atkin, 2008). According to Cox and Thompson (1997, p. 132): "*…Standard forms of contract are nothing more than instruments used by the parties* *to seek strict liability and attach blame to events as they occur. Nevertheless, the industry's hands are tied to the standard forms and their traditional methods of contracting, even though they do not deliver satisfactory results. These methods, when linked with the prevailing adversarial culture and fragmented structure lead the parties away from 'trust' towards self-seeking interest ('opportunism')".*

Nonetheless, Eriksson and Laan, (2007) suggest that the deep-rooted practice of using standard contracts in construction is only harmful, if they are used as "*safeguards*" in the absence of strong "*relational norms*". Without good relationships between the project-parties, once a default occurs, they are most likely to refer back to the clauses of the standard contract which, in turn, may encourage opportunism and lead to adversarial ways of working (i.e. remedies of damages through legal actions). A recent example of this in the UK occurred in signalling renewal contracts for London Underground reported by Connor (2014). The first project went significantly over budget and programme along with technical difficulties. The same team, technology and contract conditions were used on a second project which finished significantly ahead of schedule and under budget. The project team attributed this success to putting the contract in a drawer and concentrating on working together to solve problems. This experience certainly questions the usefulness of contracts in production and emphasises the divide between the creative, problem solving delivery process and the safeguarding commercial process as described by Sarhan *et al.* (2014). This separation was confirmed independently through discussions with a large engineering design consultancy beginning to engage with lean. Team meetings had revealed a significant difference in the understanding of purpose across the business – one of the most useful aspects of bringing people together from different departments within the organisation to have conversations around purpose was the resulting changed perceptions about the business. This also confirms that project design and delivery becomes effective when it comprises a set of conversation acts rather than relying on documented directives.

CONSTRUCTION PROCUREMENT

In construction, there seems to be two general approaches to selecting a procurement system. The first would focus on designing a project organisation structure including a project operating system based on project needs and priorities, and then adapting a contractual arrangement that aligns the commercial interests of the project parties (e.g. Thomsen, et al., 2010) - a production oriented approach which aims to design and enhance flow processes. The second is a risk based approach which is mainly concerned with overcoming transactional governance problem and considers 'risk' to be the main criterion influencing procurement selection decisions. Advocators of this approach (e.g. Hibberd and Basden, 1996), cited in Love, Skitmore, and Earl, 1998), suggest that contractual arrangements should be primarily conducted for risk allocation and mitigation purposes. Thus, a debate exists in literature upon whether procurement arrangements should be adapted to support production system requirements or tailored to transactional characteristics.

In construction, there is no ready-made product to buy (Eriksson and Laan, 2007). Both the client and the project-supply-chain have to interact in order to create the final product. Hence, there are substantial trends towards collaborative ways of working as a means for improving project outcomes; it is therefore important to consider how construction clients and companies tend to protect (safeguard) their project-specific assets, against opportunism, during procurement procedures. Very little, if any studies, have sought to question the efficiency and effectiveness of safeguards crafted by contracting parties in construction procurement. Based on a comprehensive literature review various safeguarding approaches were identified (Table 1) and their impact on project performance and outcomes are analysed (Fig. 2).

Table 1: A categorization of various safeguarding approaches within construction procurement according to their underpinning theoretical perspective and level of prevalence

Conventional safeguarding approaches based on 'risk allocation' considerations	**Less prevalent safeguarding approaches based on 'process flow' considerations**
Standard forms of contract	Relational contracting
Use of Disclaimer/Exculpatory clauses	Shared risks and rewards
Traditional insurance arrangements	Single project insurance
Collateral warranties	Latent defects insurance
Surety/Performance bonds	Pre-qualifications, direct negotiation, and IPD (e.g. Thomsen *et al*., 2010) - thus, no need for the use of bonds
Lump sum and BoQ pricing systems	Collaborative costing e.g. TVD (See e.g. Zimina, Ballard, and Pasquire, 2012)

The 'risk averse' safeguarding approaches based on transactional considerations offer little incentive for cooperation to emerge; instead they entrench wasteful processes across the supply chain and throughout the project life cycle (e.g. opportunism, unnecessary premiums, claims and disputes). By tailoring procurement decisions to 'transactional' characteristics, clients (or focal companies) concentrate on formal risk allocation, through contractual arrangements, in an attempt to maximise their own profits; thereby neglecting the significance of maintaining and enhancing the flow of production processes, and overlooking the interdependency between project partners in their efforts to maximise value.

CONCLUSION

Conventional safeguarding processes adopted by construction clients while deciding on their procurement options often complicate the problem rather than solve it. This study identified a number of imperfect taken for granted safeguarding techniques (Table 1) which stifle cooperation, lead to unnecessary costs, and entrench wasteful processes across the supply chain and throughout the project life cycle. It seems that clients and decision makers, in their attempt to overcome the safeguarding problem, mainly focus their attention and efforts on reducing ex-ante (i.e. pre-construction phase) transaction costs while giving less attention to the impact of their chosen procurement arrangements on ex-post costs. In that way, procurement decisions tend to be ultimately focussed on contract administration and shifting risks; and, arguably, risk aversion often distracts attention away from core efficiency purposes (Williamson, 1985). That steps are taken to avoid risk and minimise cost seems to satisfy the need for decision makers to be accountable regardless of the effect of these actions. This continuing adherence to imperfect conventional procurement procedures is also due to institutional pressure exerted from third parties (e.g. consultants, quantity surveyors, lawyers, insurance companies, banks) who may have a vested interest (i.e. social and/or economic motivations) for the wide-spread use of these inefficient procurement procedures. These factors combine to create the coherent current model for construction project delivery and their identification will help the development of new business models that embrace lean.

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IMPLEMENTATION STRATEGIES IN LARGE INFRASTRUCTURE PROJECTS

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ABSTRACT

Clients want to improve the innovation and efficiency in infrastructure projects, and thereby reduce time and money spent on construction and maintenance. The purpose of this paper is to present and compare experiences with new implementation strategies in infrastructure projects, and to identify how the different strategies contribute to innovation and efficiency. As the complexity of infrastructure projects are increasing along with their magnitude, there is a need to gather international and national experiences with untraditional implementation strategies. This will result in a recommendation to which strategies that best fit a complex, large-scale project.

The results are based on a literature review and case studies, hereunder document studies and interviews with key personnel from the cases. Investigated implementation strategies and types of contract involve use of competitive dialogue, public private partnership-arrangements, design and build with maintenance responsibility and partnering.

Strengths and weaknesses of the investigated implementation strategies have been charted based on experiences from large-scale projects. The paper concludes that the investigated strategies fall short of providing the desired focus on innovation.

KEYWORDS

Implementation strategies, complexity, waste, infrastructure, value

INTRODUCTION

According to Rizk and Fouad (2007), infrastructure projects are traditionally implemented as Design-Bid-Build contracts where the contractor holds little or no responsibility for the planning and design. The complexity of the projects as well as the clients' desire to influence decisions has led to a shift in strategy (Herbsman, Tong and Epstein, 1995). According to Molenaar, Songer and Barash (1999) the public sector has moved away from the traditional design/bid/build strategy towards a design/build. As this strategy has become one of the favourable methods, the timesaving is seen as the greatest advantage (Ibbs et al., 2003). There is a general need to improve the quality of infrastructure, the speed of the implementation and

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also reduce time and money spent on maintenance. Innovation is thus needed in all stages of the implementation process.

The purpose of this paper is to present and compare experiences with new implementation strategies in infrastructure projects, and to identify how the different strategies contribute to innovation and efficiency. This will result in a recommendation to which strategies that best fit a large-scale project of great complexity. Norwegian experiences with implementation strategies are collected through five case studies, while international experiences are gathered through a literature review. Types of strategies include partnering, competitive dialogue, design and build with maintenance responsibility and public private partnership-arrangements.

The Norwegian Public Roads Administration (NPRA) plans to replace seven different ferry services with fjord crossings along the highway route E39. The route runs along the western coast of Norway, a distance of almost 1100 km, and the total costs are estimated to be around 268 billion NOK. NPRA want innovation and increased focus on efficiency in the project. The research question is:

- How do the investigated implementation strategies contribute to innovation and efficiency in complex, large-scale projects?

RESEARCH METHOD

The research was carried out as five case studies, to see events in the context of the real world, but with the lack of clear boundaries between them (Yin, 2014). A project organization gives concrete boundaries for the case studies. The selection of cases was based on what implementation strategy was used, and can be seen in the following table.

Table 1: Selected Cases

Project name	Implementation strategy	Informants	Cost
E6 Trondheim – Stjørdal	Competitive dialogue	NPRA: project manager Contractor: project manager	750 mill NOK
E6 Helgeland Nord	DBOM and competitive dialogue	NPRA: project manager Contractor: costing manager	1630 mill NOK
E18 Grimstad – Kristiansand	PPP	NPRA: project manager Contractor: project manager	3300 mill NOK
E39 Lyngdal – Flekkefjord	PPP	NPRA: project manager Contractor: project manager	1200 Mill NOK
E39 Klett – Bårdshaug	PPP	NPRA: project manager Contractor: costing manager	1450 mill NOK

The strength of the case study method is the use of several types of data (Yin, 2014). Leading up to this article, a literature review, document studies and interviews were conducted. The literature review focused on the international experiences, and what advantages or disadvantages have been reported. The approach was to search for keywords (see table 2) in databases including Google Scholar, Compendex and Bibsys ASK.

Table 2: Keywords and combinations

Keyword	In combination with
Implementation strategy Contract types Contract strategies	Infrastructure Innovation waste and/or efficiency

A project document study was preformed, supporting subsequent interview findings of national relevance. Yin (2014) argues that the most important use of documents is to corroborate and argument evidence from other sources. Two reports from NPRA[6] on experiences from the new implementation strategies were found relevant in the document study, and four previous Norwegian master thesis's on the subject.

Ten interviews with project managers and project owners on the selected cases were conducted, as described in table 1. The interviews were conducted with the intention to provide a better understanding of the literature, and thus provide debt to the analysis (Yin, 2014). Depending on the implementation strategy used on the projects, different questions were asked. The interview guide containing the interview questions is found as an attachment in Opsahl (2015). A common denominator was how the informants experienced the implementation strategy along with any negative/positive aspects. The interviews were semi-structured, enabling the conversation to run more freely. In retrospect, to validate the information from the literature and reveal new aspects of the strategies more interviews could have been conducted. The intention was for the informant to give his or her own reflections on the subject matter, as these are not always displayed in a formal report (Yin, 2014).

THEORETICAL FRAMEWORK

The principle of Lean thinking is strongly connected to the reduction of waste, or more specifically the reduction of activities that use resources without creating value for the project (Womack and Jones, 2003). The idea is to do more with less. Shah and Ward (2007) propose that the main objective of Lean production is to eliminate waste through the reduction of variability. In the following, the term “innovation” describes development and use of new technical solutions.

Value for the customer in infrastructure projects is linked to the lifecycle of the project. To see design and construction in relation to operations and maintenance allows the contractors to take the Lifecycle Costing (LCC) into consideration. Lifecycle Costing is defined by the standard ISO15686 as a technique to make cost

[6] “Vegutbygging i Offentlig Privat Samarbeid. (Road construction with PPP).” 2012. (Available at http://www.vegvesen.no/Vegprosjekter/Om+vegprosjekter/OPS-PPP)
“Kostnadsreduksjon i byggeprosjekter. (Cost reduction in construction projects).” Letter to Ministry of Transport and Communication 24.11.2014

assessments over a specific period of time, taking all economic factors into consideration.

This paper uses "implementation strategy" as a term describing how the project shall be implementet, and it involves procurement, construction, operation and maintenance. Here, the actual issue is how innovation and efficiency is facilitated for in these processes.

The term "megaproject" originates from the large-scale, complex projects with a typically cost frame of 1 billion USD (Flyvbjerg, 2014). Fiori and Kovaka (2005) use the term megaproject when a project is of magnified cost, extreme complexity and has a high visibility. Flyvbjerg (2014) highlights the advantage of the large-scale construction sites on megaprojects. This enables the contractor to work simultaneously at several project sites, taking advantage of equipment surplus and unoccupied work force. Hence, the contractor reduces waste.

Early contractor involvement is part of the Lean Project Delivery (Jørgensen and Emmitt, 2009). The integrated project organization is responsible for design as well as construction. Through early involvement of the contractor the design can be influenced, improving the overall performance of the project in terms of implementation time and cost (The AIA, 2007). Kadefors (2004) states that an early development of project-wide communication and relations will facilitate a better collaboration.

Competitive dialogue aims to align the demands from the customers with the solutions chosen by the use of the contractor's knowledge and innovation (Hoezen et al., 2010). It is a flexible procedure that allows for the client to discuss all aspects of the project with the contractor (Hoezen and Dorée, 2008). In complex projects this is an advantage for both parties, as it can facilitate innovation through interaction and cooperation. After the dialogue is closed and the preferred bidder chosen, no substantial modifications should be made. This paper defines competitive dialogue as the procurement form where a dialogue is initiated before the preferred bidder is chosen, according to Hoezen and Dorèe (2008).

The chances of discovering future problems in the projects are enhanced by the dialogue phase (Hoezen et. al., 2010). This reduces the risk and uncertainty for both the client and the contractor. However, the risk is increased for both parties compared to the traditional Design-Bid-Build, as more contractors negotiate before the preferred bidder is chosen. Hoezen and Dorée (2008) state that trust-based collaboration is important in execution of competitive dialogue. The dialogue is conducted with each contractor individually, and the client must be careful to maintain confidentiality of the tenders.

Public private partnership-arrangement (PPP) is a contractual relationship between government and industry, in this case a contractor, to deliver a public facility (Papajohn, Cui and Bayraktar, 2011). The private company makes the capital investment, and the public authority will reimburse this investment throughout the contract period (most commonly 20 to 30 years). During the operational phase, revenues are intended to cover the financial investments as well as costs of construction and operation, but not the maintenance. A fee will apply if the finished project does not deliver in accordance to expected performance standards. The aim of PPP is to see the cost of construction in relation to the quality and lifecycle costs of the project (Papajohn, Cui and Bayraktar, 2011). The public sector is still responsible for the availability of the service or facility, but the operational responsibility lies with the private company. As the Norwegian definition is similar to the definition of Papajohn, Cui and Bayraktar, (2011), this paper uses their definition of PPP.

The most important part of a PPP contract is how the risk is split between the parties (Iseki and Houtman, 2012). In general, the public authority carries the risk related to overall planning and the users' need for the project. The private company holds the risk related to the design, operation and maintenance, as well as the financial and technological risk. As the private company carries the full responsibility for design, implementation and operation, the PPP contract implies increased focus on cost efficiency and innovation (Resor and Tuszynski, 2012).

In the Design Build Operate Maintain contract (DBOM) one contractor is responsible for design, construction, operation as well as the maintenance for a set period of time while the ownership remains with the public authority (Dahl et al., 2005). The focus lies on the project to meet the set performance standards, by reducing the gap between design and construction (Priemus, 2009). The project is seen as a whole, and this implies a reduction in number of contracts between the client and different contractors. To help design keep focus on the operation and maintenance, contract structures and design strategies should be applied with great consideration (Dahl et al., 2005). This paper uses the definition of Dahl et al. (2005).

In many ways this implementation strategy is similar to PPP, but they differ in the way the project is being financed (Dahl et al., 2005). The contractor still carries the risk for the condition of assets, but the client pays revenue to the contractor to cover the cost of development and construction during the implementation phase.

If the conditions are right for a DBOM project, Priemus (2009) says the price can be improved, and more innovation can be brought to the table. Preconditions would be professional behaviour from the involved parties, a culture for innovation and a complex project with little interaction with the environment. Lee, Tommelein and Ballard (2010) link the use of a set of lean practices to the success of the application of this implementation strategy, and thus the reduction of waste.

Partnering consists of collaboration on commercial terms between participants from the client and the contractor to continuously improve the performance (Bennett and Jayes, 1998), and this definition will be used in the following. According to Thomas and Thomas (2005) a higher value can be achieved by using an integrated team approach to reduce waste of resources.

The intention is that early involvement of the contractors and consultants shall improve the cooperation within the project organisation. Thompson and Sanders (1998) claims the benefits of partnering increase along with the development of the relationship between the parties. Partnering thus depends on "the right combination" of participants in the project group (Thomas and Thomas, 2005).

FINDINGS

Findings from the literature review, document studies and the interviews for each implementation strategy are presented separately.

The literature review confirms the benefits from using competitive dialogue when there is a lack of a clear project description or the project is particularly complex. The client can utilize the expertise set in the contractor´s organisation to improve the outcome of the design process. Formulation of the functional descriptions should not restrict the solutions in order to allow for innovation to evolve. The risk of not winning the procurement is significant for the contractor, but the document study reveals a reduction in the number of tenderers as a possibility.

The document studies show that it is beneficial to use the contractor's expertise in complex projects. The innovation in the industry seems to be greatest when using competitive dialogue. However, regulations imposed by the client, in these cases the NPRA, will still limit the innovation. All the informants pointed out that better solutions make up for the extra time spent in the dialogue phase. According to the informants, there is little focus on operation and maintenance when developing solutions. This needs to be cared for in the contractual terms.

There was unanimous consent amongst the informants about the high value of the early initiation of the communication flow as a result of the early contractor involvement. Informants from both parties highlight the forming of communication patterns and development of trust. Faster communication implies less waste in the implementation phase. Further on, the informants from the contractors stated that the preapproval of solutions presented through the dialogue phase reduced the need of amendments during construction.

All the informants brought up the high cost related to the dialogue phase of the project. Giving the contractors a compensation for their time and resources spent might solve this problem. According to the document studies, the compensation should as a minimum cover the cost of external advisors as well as to some extent the internal resources spent.

The document studies pointed to the biggest potential for increased value in PPP being the shift of responsibility[7]. As the contractor holds full responsibility for both the design and the construction, the possibility arises for a speed-up of the construction. This possibility might contribute to a faster completion of the construction phase, but the document studies showed it can also turn out to be counterproductive in terms of late preapproval of solutions by the client[8]. In a report[9] on the Norwegian experiences, it is pointed out that the most positive effects from PPP are the expected increase in efficiency and a shortening of the construction time.

Informants from the contractors claim that standard solutions often are chosen over innovation in order to reduce the contractor's risk. Solutions are often chosen based on the total cost. The question remains why innovation is avoided, as risk alone cannot be the only factor. Avoiding cost associated with developing new solutions might be an underlying factor, but the informants refused to confirm this statement, nor deny it.

The interviews show that early involvement of the contractor is believed to reduce waste in the construction phase. Due to the responsibility for the project from design and through operation, the informants from NPRA highlight that changes in scope are fewer and of lesser impact.

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7 "Offentlig Privat Samarbeid (OPS) og innovasjonspolitikk. (PPP and innovation politics)." Vista Analyse AS, 2008

8 "Kartlegging og utredning av former for offentlig privat samarbeid (OPS). (Investigation of forms of PPP)." Ministry of Trade, Industry and Fisheries, 2003

9 "Evaluering av OPS i vegsektoren. (Evaluation of PPP in the NPRA)." Dovre International AS and Transportøkonomisk Institutt, 2007

A Norwegian report[10] states that the enhanced risk taken by the contractor in DBOM concerns the industry. As this is part of the incentive to keep operational costs low, informants from NPRA does not share this concern with the contractors. The allocation of risk for operation to the contractor should imply a reduction of scope changes during the operational phase.

The reduction in the number of contracts to only one large contract proves by the literature review and the document studies to be one of the biggest advantages for the client. An incentive is given to the contractor to see the design and operations in connection. The contractor assumes a high risk in terms of the need for maintenance and poor construction works when holding responsibility for the operational phase.

One can assume that innovation is being facilitated by the need for maintaining a high quality and designing for low maintenance costs. Interviews conducted with informants from the contractor states the opposite, as standard solutions are more often chosen to avoid the risk of untested solutions. The limitations imposed by the client are pointed out as an obstacle for innovation, as new solutions would have to be preapproved and thus extends the design phase. This again limits the contractor’s possible profit, and is seen as a huge downside.

As an implementation strategy, partnering involves an increased collaboration between the parties. According to literature, the benefits of this are how the project owner can utilize the knowledge of the contractor to find the best solutions.

Previous student work[11] states that the model is seen as more demanding in terms of involvement, but the gain is a more efficient building process. Early contractor involvement will be beneficial for complex projects, and thereby partnering can be useful.

Several factors need to be present in order to generate a well-functioning partnering process, according to the document studies. The right mind-set of the participants is a key to ensure full commitment. A translucent economy, or open book economy, is important to enhance the trust between the client and the contractor.

Interviews conducted show that there is an overall consensus that partnering provides an increased value for the project. In terms of innovation, the opinions are divided. Some informants claim that even though the early involvement implies that innovation should occur to a large extent, the reality is the opposite. Partnering becomes a way of developing efficient communication patterns and thus facilitates for innovation.

DISCUSSION

The early contractor involvement is of essence in the use of competitive dialogue if the project is to create the innovative solutions desired in complex projects. This interaction leads to a common objective for the project and an early initiation of communication. Hence the project can experience a reduction of duplicated work and design errors, consistent with the principles of Lean. Cohesive staffing will be an advantage to ensure the up-keep of the communication flow from the dialogue phase.

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[10] “E6 Helgeland, Korgen – Bolna (KS2).” Dovre International AS og Transportøkonomisk Institutt, 2013

[11] M.Sc. thesis, Department of Civil and Transport Engineering, NTNU

The dialogue phase seems to provide a better economical control, based on the joint development of solutions. The latter will be a huge positive effect for the client, as cost overrun tends to be an issue with infrastructure projects.

On the negative side no reduction of operational costs is seen, as the contractor claims to have no knowledge of the lifecycle costs of the new solutions. As these costs should be easy to estimate, unwillingness to adopt new solutions is more likely to be the underlying issue. To make the strategy more profitable and thus more attractive for the contractors, the compensation should be of such size that participation in the dialogue leads to economical gains for the contractor.

In terms of PPP and DBOM, one can state the following positive experiences: The construction time can be expected to be shortened due to parallel design and construction, private financing (in PPP) and the possibility to better make use of the resources. Quality is still expected to remain high due to the contractors' responsibility for operation. In megaprojects this will contribute to lower the lifecycle costs, as maintenance costs will be reduced. Waste is assumed to be reduced as the number of interfaces is less, but this is just an assumption based on the literature review, and is not confirmed in any of the conducted interviews.

Of the negative experiences the findings show that innovation is not increased in these strategies, it is rather the opposite that happens as the contractors choose standard solutions to avoid risk. The limitations imposed by the client in terms of preapproval of solutions are connected to this challenge. The intention to lower the maintenance cost and increase quality, depends on design freedom. Innovation is not increased until a solution is found to this contradiction.

From the findings we have that all projects can benefit from using partnering, but especially projects where the project scope is hard to define. For a megaproject, one can assume that the complexity is not merely of technical difficulty, but also depends the magnitude of the project. Hence, partnering would be highly profitable in megaprojects. Furthermore, when the client sees it as beneficial to develop the project together with the contractor in terms of innovation, partnering should be considered.

CONCLUSION

This article seeks to give a recommendation in terms of how to implement megaprojects. Together with efficiency, innovation is an important issue in these projects, as there are few similar projects to gather experiences from. In terms of the highway route E39 with the seven fjord crossings, an underlying issue is how to achieve the desired innovation in the project.

As a summary, it can be stated that the new implementation strategies contributes to the reduction of waste during design, construction and operation. Designs are conducted to improve constructability through an early involvement of the contractor as well as better communication between the parties in accordance to the principles of Lean. This improvement of efficiency is an expected result. On the opposite side, the common denominator of the negative experiences seems to be the lack of facilitating for innovative solutions. The contractors lack the freedom to come up with new solutions and fear the attached risk, and thus the industry is merely moving sideways as opposed to forward in terms of innovation. As this is one of the main objectives of the investigated implementation strategies, it is a rather important issue to address in further research.

For the fjord crossings along the E39 highway route, the desired innovation in the project needs to be addressed. Partnering might be seen as the obvious choice, but according to the interviews conducted in this article, innovation is not really present in this strategy, nor is it in PPP or DBOM. By early contractor involvement, the possibility for innovation as a result of the contractor's competence and experience arises. A better way to ensure innovation in the solutions is thus by the use of competitive dialogue.

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BIM AND LEAN

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BIM AND LEAN IN THE DESIGN-PRODUCTION INTERFACE OF ETO COMPONENTS IN COMPLEX PROJECTS

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ABSTRACT

This paper presents a case study on a complex construction project that demanded a great level of prefabrication in order to meet a fast schedule and to overcome logistical challenges. The study was carried out with a mechanical contractor firm developing a series of Engineered-to-Order (ETO) components for the project. The objective of the research was to study the possibility of devising an integrated approach for production planning and control for this ETO environment. Two papers report on this research. The first one describes the methods used to plan in an integrated manner the prefabrication, delivery, and installation of ETO components at the job site. This second one discusses the use of BIM to support such integrated management and the challenges faced during its implementation. Finally, the paper describes how the team used lean construction principles to overcome some of these challenges. The contributions of this paper include, first, articulating challenges faced when using BIM on a complex project as a support to managerial practices and, second, illustrating the use of lean principles in the design-production interface as a means of leveraging BIM.

KEYWORDS

Building information modeling (BIM), complex projects, design-production interface, engineered to order (ETO), industrialization, production planning and control.

INTRODUCTION

Some construction projects present a high level of complexity as they are one-of-a kind products requiring multidisciplinary design and involvement of numerous parties in their supply chain. Demand for fast delivery and the logistical challenges associated with that demand contribute to increasingly larger proportions of

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building's components being fabricated and preassembled offsite (e.g., Eastman, et al., 2008). Often, these one-of-a-kind projects require customized design and fabrication of Engineered-to-Order (ETO) components. Unlike off-the-shelf parts being mass-produced, ETO components demand sophisticated engineering and careful collaboration between designers, fabricators, and installers. The design of such components also requires different disciplines to work together to ensure that the building systems are properly integrated and installed. The environment in which ETO components are produced comprises of a series of production units, i.e., design, fabrication, and installation. These different production units need to be integrated so that they will deliver the desired value while avoiding waste and rework: the right components need to engineered, fabricated, and available for installation at the time they are needed at the construction site. The importance of developing a so-integrated production planning and control system for ETO environments has been emphasized in previous research (Little, et al., 2000), however, the challenges encountered in this specific context are yet not fully understood (Viana, 2015).

The research presented here focuses on analysing the challenges of managing ETO components used in a complex and particularly fast-paced construction project. The study was conducted in partnership between the Project Production Systems Laboratory (P2SL) at UC Berkeley in the US, NORIE at the Federal University of Rio Grande do Sul in Brazil, and Superior Air Handling, a US mechanical contractor specialized in the market niche of complex construction projects. The objective of the research was to study the possibility of devising an integrated approach for production planning and control for the different ETO components under the mechanical contractor's scope. Two papers report on this research. The first paper (Viana, et al., 2015) describes the approach used to integrate the prefabrication, delivery, and installation of ETO components at the job site. This second paper discusses the challenges faced in the design-production interface and the role of the use of BIM combined with the adoption of lean principles to support that transition.

DESIGN-PRODUCTION INTERFACE OF ETO COMPONENTS

Bertrand and Muntslag (1993) describe the production environment of ETO components based on three aspects: dynamics, uncertainty and complexity. Although they adopt the perspective of companies that manufacture ETO components, past research in lean construction has used such framework to understand the challenges of managing ETO in the context of construction projects. Viana (2015) demonstrated that vast amounts of waste (i.e., waiting time and rework) get generated when fabrication and site installation are not managed using an integrated production planning and control system. Sacks, Akinci and Ergen (2003) emphasize the importance of exchanging real time information between installation and fabrication; furthermore Tommelein (1998) stresses the importance of establishing a pull system to control production. Within this context, the importance of managing the design phase of ETO is highlighted in the literature (Bertrand and Muntslag, 1993) especially because uncertainty inherent in the design phase hinders the ability to predict the overall lead times of these components.

Little empirical evidence was found to understand the challenges faced in this less tangible phase and what kind of managerial mechanisms can support the design-production interface of ETO components. Nevertheless, two potential managerial solutions were identified in the literature: BIM and the adoption of lean principles. Eastman, et al. (2008) advocate that BIM can help transition ETO components from design to production as it allows for rapidly verifying constructability and coordinating all building systems prior to producing each piece. The benefits of fabricators and subcontractors using BIM include, e.g., use of standard components and details; automated estimating; reduced cycle times for detailed design and production; elimination of design coordination errors; lower engineering and detailing costs; data to drive automated manufacturing technologies; and improved preassembly and prefabrication.

In addition, different authors stress the need to manage the design process in order to start the production phase successfully. Koskela, Ballard and Tanhuanpää (1997) argued that even when there is an optimal sequence of design tasks, internal and external uncertainties tend to push the design process away from that optimal sequence, leading to low productivity, prolonged duration and decreased value of design solution. They presented two methods to support design management, (1) the Design Structure Matrix (DSM) and (2) the Last Planner System (LPS), and they experimented with both in practice to support design management. However, regarding the combination of BIM with lean principles to manage design, we found evidence only about the use of some components of LPS and BIM in Khanzode, et al. (2006) and Khanzode (2010). Khanzode (2010) presented different case studies in which some components of the LPS were adopted to support BIM coordination with MEP subcontractors. Nonetheless, despite presenting empirical evidence, Khanzode mentions little about the complexity and uncertainty of the studied projects and no studies were found specifically about ETO environments.

EMPIRICAL STUDY

The analysed construction project is a large commercial building of approximately 300.000 m2 to be built in 3 years. Due to the fast pace of construction, the project demanded a high level of prefabrication. For the mechanical contractor, whose fabrication facility is located out-of-state, that meant establishing partnerships with local fabricators to meet the site demand. The responsibilities of the mechanical contractor included: review engineering drawings, submit equipment for approval, coordinate engineered components with other building systems, fabricate, manage the delivery and execute the installation. The first two authors’ role in the project was to support the mechanical contractor’s team with the implementation of the LPS to transition from the design revision phase to the fabrication- and installation phases. That effort started in March 2014, and in mid-August 2014 the joint effort involving the aforementioned research laboratories was initiated to investigate the opportunities of using an integrated management approach for the ETO components.

Data was collected over the course of 1 year to understand the activities and challenges related with the transitioning stage from design to production of ETO components. One important source of evidence was a series of interviews with team members and analysis of project documentation, especially related to the mechanisms used to support the transition from design to production, e.g., BIM and lean managerial techniques. Another important source of evidence was the participation of the researchers in meetings. Those meetings included: (a) project meetings, i.e., model coordination meetings, pull planning sessions, meetings to review issued design changes; (b) meetings with fabricators, i.e., co-design meetings, preparation for fabrication meetings, prototyping and testing; and (c) internal company meetings, i.e., production planning, LPS meetings and meetings to status internal progress.

CHALLENGES IDENTIFIED

The analyzed project presented a high level of dynamicity, uncertainty, and complexity, as defined in Bertrand and Muntslag (1993). The observed sources of dynamicity related mainly to a phased approach used by the owner to procure the project and the need for the mechanical contractor to cope with increased demand of additional scope if and when selected to build other project phases. The observed sources of complexity were myriad; however, the most evident was the involvement of an intricate supply chain to produce each ETO component. Such complexity can be exemplified, e.g., with the installation of control devices by another trade during the fabrication of the components, and with the combined electrical and mechanical racks that required close collaboration between these different subcontractors upfront to allow for their design and prefabrication. Finally, uncertainty was a major challenge to the successful installation of ETO components in the project. Two major sources of uncertainty were observed: (a) fragmentation in the procurement of design and installation; and (b) frequency and scope of design changes. The latter two sources are further discussed in the following paragraphs.

Figure 1 charts a timeline with design changes and the contractual situation of the mechanical contractor, reflecting the uncertainty during that period. The mechanical contractor held a design-assist type of contract as of April 2013. Around October 2014, the Guaranteed Maximum Price (GMP) for installation started to be negotiated. Some of the ETO items needed to be installed while the contract scope was still being negotiated and before the final contract was signed. The chart also shows an analysis of design changes that happened during that period. Data was collected until March 2015. Since the contract for pre-construction services was signed in April 2013 until March 2015 (last available data) 86 changes were issued to the bid set drawings, affecting the mechanical components. While some design changes were owner-driven changes in program and scope, others stemmed from to the need of further design clarification in a specific area, and were triggered by the General Contractor (GC), architects, engineers or subcontractors evaluating the constructability of the design bid set.

Uncertainty in design was also a consequence of different subcontractors joining the project in different times. Two problems were observed: (a) when the detailing team of a specific discipline was not yet in the project to participate in modelling coordination; (b) when the detailing team was in the project but no installation contractor was on board to verify if the design was constructible. As a result, placeholders with estimated dimensions were allocated in the model whenever detailing teams were not on board and detailed design would be verified only later by installers. This caused a delay in finalizing model coordination and resulted in a high level of rework. On a few occasions, problems were faced during field installation, when fabrication drawings were released early due to time compression without being fully coordinated and verified.

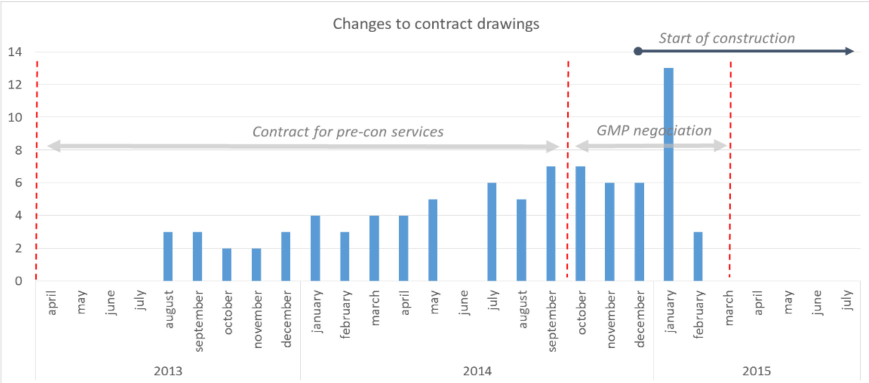

Figure 1: Design changes issued from bid set to GMP negotiation

For the mechanical contractor, uncertainty in the design phase related to scope changes resulted in an extended speculation period with fabricators, and delayed decisions on fabrication strategies. Staying too long in the speculation phase and accordingly pushing the firming-up of fabrication contracts (too) close to installation could also raise threats of increased costs for raw material and of challenges in qualifying the additional workforce needed to fabricate the components in a short lead time. Even when design changes did not cause scope changes, they represented a challenge for planning and producing ETO components. Figure 2 demonstrates that design changes may compress the time available to produce these components. The chart presents the total lead time to take one of the components from detailed design to installation. When the expected time for design completion gets delayed, it pushes forward all the predecessor activities preceding installation. If the installation date remains the same, that schedule compression can undermine important activities between these two phases, i.e., testing, prototyping, prefabrication, and constructability assessment.

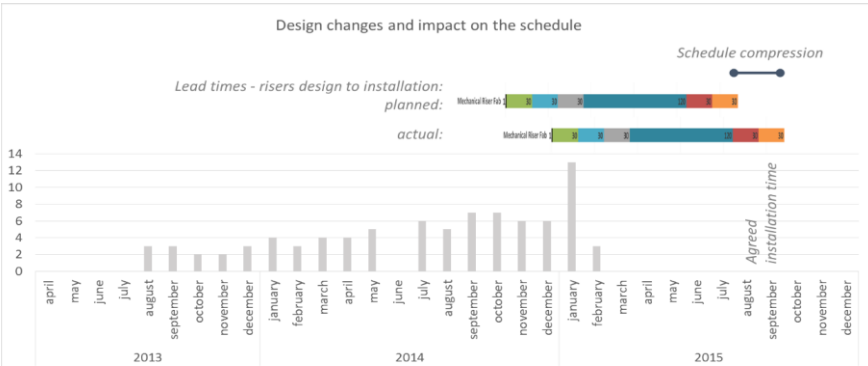

Figure 2: Design changes and impact on time to deliver ETO component

Figure 3 details the process taking issued design changes to the point of generating fabrication drawings. It was observed that not only activities have a long or unknown duration, but also they can be repeated several times. This makes it very difficult to predict when a design will be finished and fabrication drawings can be released. Especially when project participants are located in different parts of the world, the return time for answers and approvals can be even longer. In addition to that, owners' involvement in the selection and approval of material and equipment suppliers can also bring additional complexity. Every time a change is issued, the 3D model needs to be updated and re-checked against requirements, e.g., constructability, fabrication, aesthetics, functionality, and seismic requirements. This causes a series of iterative loops that makes it difficult to track design progress towards completion and brings the threat of having a complete design only after components have already been released to fabrication based on an outdated design and/or a mismatch between design and what was installed on site. Given the high level of uncertainty and its potential impact on the successful production and installation of ETO components, the importance of monitoring possible schedule compressions and managing the design-production interface became evident. The next session presents mechanisms that were used on the project for managing the design-production interface of ETO components.

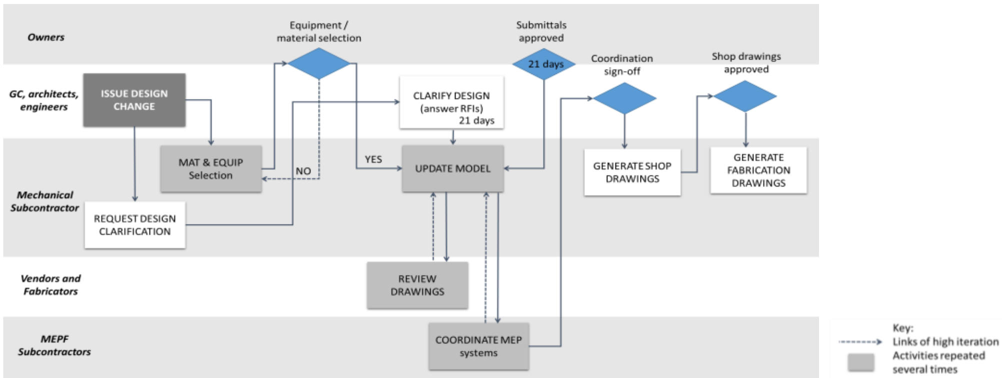

Figure 3: Process from design changes to fabrication drawings

BIM INITIATIVE

Use of the BIM model was key in supporting the transition from design to production of ETO components. BIM not only supported the team when confirming the constructability of the designed systems faster, but also refining the solutions with fabricators and storing important information that would later facilitate production planning and control.The design of ETO components required an intense iterative process of refining solutions based on ease of fabrication and degree of constructability in the field. Apart from the benefits of clash detection, the BIM model was extensively used to support production planning with other trades and the GC. The ETO components offered unique solutions developed particularly for this project and had never been installed on any project before. Being able to simulate their installation through BIM while verifying logistical challenges, interference with other building systems, available space for installation and preferred installation sequence in intricate spaces were some benefits of using BIM.

A key enabler of using the model for production planning was the familiarity of superintendents with the model, the level of detail in the model, and the availability of superintendents to participate not only in production planning meetings but also in BIM coordination meetings. BIM also enabled relevant information to be analyzed, i.e., linear meters and kilograms of sheet metal (feet and pounds) to serve the purpose of productivity tracking and cost estimating for raw materials, thereby facilitating production planning and control in the factory and during field installation. The model made it possible to extract layout points to be used in the field, automating and reducing errors in layout activities. This was possible due to the level of detail in the model, closely reflecting what was going to be built. A bar coding system was devised to track the ETO components from release to fabrication until their delivery and installation on site. This allows the mechanical contractor to track the different equipment and assemblies and it facilitates inspection for the GC.

However, we observed that not all the benefits expected from BIM could be realized, especially in regards to supporting production tracking and control. A challenge to using BIM in its fullest potential was the level of maturity of the BIM model when the team had to start fabrication. The high level of uncertainty observed in the design phase delayed the model's completion. The adoption of lean techniques supported the team to deal with this challenge, as discussed in the following section.

ADOPTION OF LEAN TECHNIQUES

Understanding the physical activities involved in the production system of ETO components was the starting point to support the management of the design-production interface. The Line Of Balance (LOB) helped to determine and visualize the pace of installation and fabrication of different components. Viana, et al. (2015) describe this topic in more detail. The calculation of lead times for producing ETO components started with understanding field demand, i.e., installation sequence and pace. Figure 4 shows the example of a specific ETO component. Each column represents a week and each line represents a different location. Installation occurs in 2 batches of 40 components, installed at a pace of 2 components per day. In order to meet that demand, prefabrication has to start 16 weeks prior to the start of installation and progress at a pace of 2 components per week.

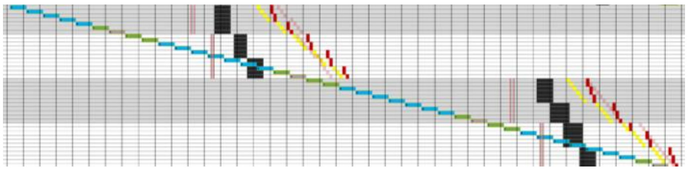

Figure 4: Visually analyzing fabrication and installation lead times

After analysing the pacing of installation and fabrication, we collected data about other activities that precede fabrication, e.g., material procurement, prototyping, and testing. The time that the factory needs to get all the raw material ordered and adjust their layout in order to meet the fabrication demand was estimated to be 6 weeks. This time includes prototyping and testing activities to identify any challenges related to logistics prior to entering full-scale production. The calculation of lead times was based on site demand, fabrication capacity, and storage availability and indicated the preferred scenario for ETO production from an economic perspective. The overall lead times for each ETO component (including fabrication, prototyping, and testing) were relayed to the GC, who incorporated this data into a tool created to support coordination efforts and identify priorities for model sign-off. Figure 5 depicts only the mechanical elements, although the tool contains information about the components from all different subcontractors.

The BIM model was composed of building geographies and those geographies in turn were divided into building blocks. The different ETO components displayed in Figure 5 were located in different blocks in the BIM model (Figure 6a) and their lead times were used to prioritize BIM coordination. A “Last Responsible Moment” (LRM) for signing-off each building block was established. This pulling mechanism based on critical fabrication lead times allowed the team to work on maturing the BIM model as much as possible without posing a risk to fabrication activities. Figure 6b illustrates that the design changes made to building blocks direct or indirectly impact the design of ETO components.

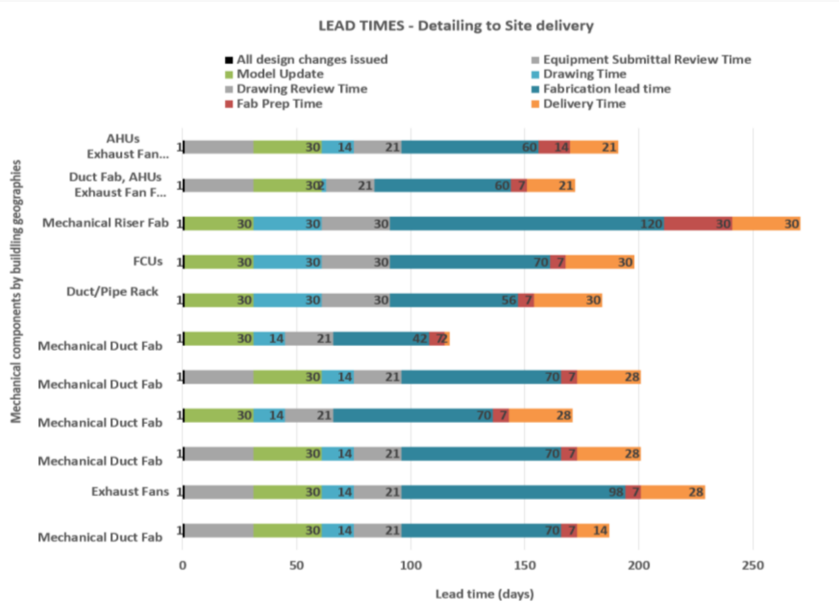

Figure 5: Mechanical components with long lead time

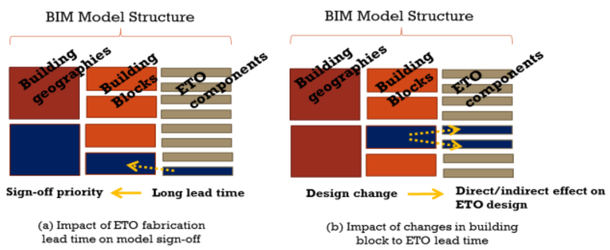

Figure 6: BIM model organization and interdependency with ETO components design

In order to mitigate such impact, the GC established a visual board demonstrating the progress of each building block towards sign-off and organized a committee for evaluating design changes. The board and the committee facilitated communication between the GC, subcontractors, and the owner. While the board had the purpose of allowing subcontractors to verify and update information about fabrication lead times, the committee played the role of communicating to the owner when and how design changes would impact cost and schedule due to late fabrication release. This understanding of impacts allowed the owner to make better decisions about desired scope changes. Also, subcontractors were able to see upfront if they would be affected by changes, so they could calculate the potential impacts and inform the GC and owner thereof. The techniques to calculate overall lead times were very beneficial to the project team and to fabricators, however, they required constant updating and verification. During the period of this study, the planned field-installation suffered some changes. As a result, priorities for fabrication and sometimes for design completion also had to be shifted. Efforts were made to keep the fabricators always up to date of the project's current situation. In this sense, by adopting the LPS internally, the mechanical contractor was able to increase the involvement of external parties in short term planning to remove design constraints and to keep track of overall progress of ETO components from design release to site delivery.

CONCLUSIONS

In this paper we investigated the topic of managing the production of ETO components on a complex project. We focused on understanding the challenges related to the design-production interface in an uncertain environment. It was observed that managing approaches for projects that use mainly ETO components need to be different from those that use off-the-shelf mass-produced components. The complexity of designing, testing, prototyping, fabricating, preassembling, and delivering these components to site poses major challenges for the successful installation of ETO components. Each ETO component offers a complex and unique solution that needs to be verified throughout the entire value stream before getting to the job site, so as to avoid mistakes that could be catastrophic. This requires a well-coordinated production system able to accommodate the participation of numerous participants in their intricate supply chain in the design and production phases, while facing high levels of design related uncertainty in the project environment.

We were able to initiate an investigation of how BIM and lean principles can support the design-production interface and help transitioning ETO components from design to production. BIM supports the fast verification of proposed design solutions and storage of information that can support fabrication and installation activities. Such fast verification was of great benefit when dealing with an uncertain environment. Lean techniques allowed for the visualization and better understanding of necessary lead times to produce ETO components, supporting increased communication among different project participants so they could produce components on time.

We observed that in order to be fully successful in an ETO environment, contractual relationships need to support the integration of design and production. However, even on a project where a fragmented approach was used for procuring design and production of certain disciplines, the combination of BIM and lean techniques were found to provide a strong basis for the collaboration required to successfully produce ETO components in uncertain environments. This paper also raises a question as to what expectations to impose on BIM initiatives. BIM can facilitate an integrated management of ETO systems but the level of detail required to support production activities needs to be planned in advance. We learned that the benefits of BIM are directly related to the level of maturity the model achieves when it is time to start fabrication. The resources required to coordinate the model should be committed to upfront and match the expectations regarding how and when BIM will support the project (e.g., to support certain activities, a greater level of model maturity is required). This topic is worth exploring in future research.

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INTELLIGENT PRODUCTS: SHIFTING THE PRODUCTION CONTROL LOGIC IN CONSTRUCTION (WITH LEAN AND BIM)

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ABSTRACT

Production management and control in construction has not been addressed/updated ever since the introduction of Critical Path Method and the Last Planner® system. The predominant outside-in control logic and a fragmented and deep supply chain in construction significantly affect the efficiency over a lifecycle. In a construction project, a large number of organisations interact with the product throughout the process, requiring a significant amount of information handling and synchronisation between these organisations. However, due to the deep supply chains and problems with lack of information integration, the information flow down across the lifecycle poses a significant challenge. This research proposes a product centric system, where the control logic of the production process is embedded within the individual components from the design phase. The solution is enabled by a number of technologies and tools such as Building Information Modelling, Internet of Things, Messaging Systems and within the conceptual process framework of Lean Construction. The vision encompasses the lifecycle of projects from design to construction and maintenance, where the products can interact with the environment and its actors through various stages supporting a variety of actions. The vision and the tools and technologies required to support it are described in this paper.

KEYWORDS

Building Information Modelling (BIM), intelligent products, lean construction, building lifecycle management.

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INTRODUCTION

Information and communication systems and novel management concepts are evolving faster than ever before enabling construction companies work more effectively and efficiently, however the industry has not been able to achieve the desired benefits (Stewart and Mohamed, 2004; Adriaanse, Voordijk and Dewulf, 2010; Kang, O'Brien and Mulva, 2013). However, most of these new concepts are developed in isolation and do not sufficiently balance the people and process aspects, and have not been able to improve the core construction processes (Dave, et al., 2008). Therefore, there lies an opportunity for building a new framework that can provide a comprehensive technological and process solution supporting construction lifecycle.

Management in construction traditionally relies on ”push” based logic, for example the production management process based on CPM (Critical Path Method), where the plans are pushed from the top (Ballard, 2000; Ballard, et al., 2002). Even though, lean production and Last Planner® are based on the "pull" logic, the predominant information delivery and control logic supports "push" based processes (Dave, et al., 2014). This coupled with the separation of product and process (production) information, and in general the separation of information from "product individual" makes information management and flow difficult across the supply chain (Kärkkäinen, et al., 2003).

This research aims to introduce a new production logic for construction, one where the control logic of production, i.e. assembling instructions, sequencing and manufacturing, and information about the product is linked to the product itself and "travels" through the production lifecycle, (i.e. from conceptual design through to construction and facilities management). As such, the proposed technologies or concepts on their own are not new, but their emergence and maturing is opportune to the development of the proposed concept for construction. The idea of product centric control (Kärkkäinen, et al., 2003) has been successfully tried in manufacturing environment, and with a limited scope in logistics process in construction (Ala-Risku and Kärkkäinen, 2006). However, the proposed vision builds on these ideas and attempts to address the construction lifecycle. The paper begins with a critical review of the current production management and its major components. In the following section the proposed solution is outlined and its major building blocks explained. A case study and potential application scenarios are presented next followed by a discussion and the conclusion.

THE VISION – INTELLIGENT PRODUCTS IN CONSTRUCTION

A product centric vision – as shown in Figure 1, where the contextual operative logic of a product individual to support the lifecycle is embedded (or linked) within individual components already from the design phase. The vision covers the lifecycle of the production process from design to construction and maintenance, where the products can interact with the environment and its actors supporting a variety of actions. This new vision will help designers focus on value provision by making available real-life, context sensitive data from previous installations, enable self-organization of construction projects, reduce the cost of owning facilities, facilitate feedback function for improving product design. For developing the new framework, we use the theory of technology as a basis together with an inside out logic; BIM as a platform for modelling product and process information; the internet of things for connecting different realities (virtual and physical); and direct connection to manufacturing. Whilst all these have been maturing separately, these concepts are now brought into one common framework.

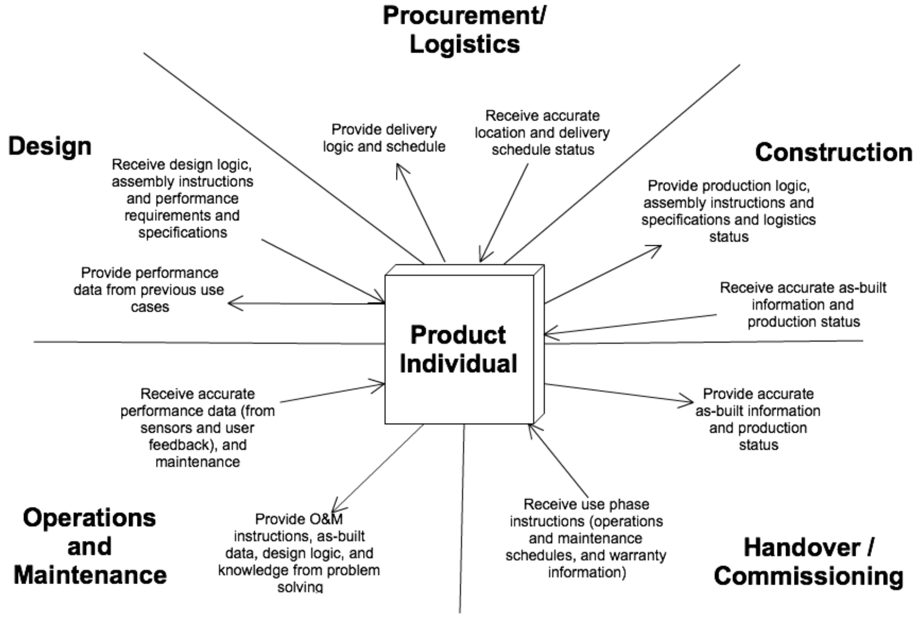

Figure 1: Product Centric Information Management (based on Kärkkäinen, et al., 2003)

CONCEPTUAL UNDERPINNINGS

Production planning and control affect construction processes directly, and have been one of the major aspects affecting construction productivity. Koskela (2000) attributes many of the problems related to the planning process in construction to the lack of an explicit theory and the predominant "Transformation" or "T" view of production. Koskela (2000) argues that this has led to the neglect of "flow" and "value" views in production and in turn has resulted in wasteful processes. The direct manifestation of this "T" approach can be seen in how the projects are organised and managed, as the activity guidelines/instructions for the next step in production are always pushed from outside of the production system (often according a CPM plan/schedule) and the flow of information is often dependent on systems external to production.

From a technological viewpoint, Building Information Modelling (BIM) has the potential to transform the way products/building elements are managed in construction supply chain (Eastman, et al., 2011; Aram, Eastman and Sacks, 2013). BIM not only provides a product modelling platform but an information management platform that can serve stages of entire project lifecycle. (Sacks, et al., 2010) have discussed the synergistic potential of lean construction and BIM across the project lifecycle. While these synergies have been realised in individual implementations and projects, there is not a systematic exploitation strategy, and a general lack of integrating technologies or systems that help realise these synergies. In particular, the aspect of information flow and communication across supply chain is the one where there are major gaps (Stewart and Mohamed, 2004; Adriaanse, Voordijk and Dewulf, 2010) . While the product centric control logic idea has been proposed and trialled for logistics process in construction (Ala-Risku and Kärkkäinen, 2006), it has not been applied across the lifecycle. Some of the main problems that the vision tries to overcome are outlined in the following section.

PROBLEMS WITH THE FRAGMENTED SUPPLY CHAIN

The construction industry is highly fragmented with a large number of small companies operating in the sector. Over the last 30 years the industry has increasingly grown risk averse and relies mostly on subcontracted workers to execute projects. (Dainty, Millett and Briscoe, 2001). Figure 2 shows the dominance of small and medium size (SME) companies in construction, where the Large and Medium size only form 0.7% of the overall proportion. This severe fragmentation in the supply chain makes it increasingly difficult for information to be synchronised and communicated at various lifecycle stages. Dainty, Millett and Briscoe (2001) report that the UK construction sector is a long way from being able to achieve true supply chain integration and that an adversarial culture is ingrained within industry's operating practices, where a general mistrust between companies prevail.

Proportion of Firms by Size Category

Size (No. of Employees)	Micro (1-9)	Small (10-49)	Medium (50-249)	Large (250+)
GB[1]	89.8	9.4	0.6	0.1
France[2]	91.6	7.7	0.7	0.1
Germany[2]				
Structural Firms Only	69	27	3.7	0.4
All Construction Firms	95			
US	81.1	16.3	2.4	0.1

1. Size bands for UK are 1-7, 8-59, 60-299, over 299
2. Medium Size Band 50-199

Source: DTI, Hauptverband der Bauindustrie, Service, Economique et Statistique, US Census Bureau

Figure 2: Proportion of Construction Firms by Size (DTI, 2004).

ALIGNMENT OF VALUE IN SUPPLY CHAIN

The above mentioned fragmentation means that a single company has typically a limited role in a construction supply-chain and it tries to capture value from upstream and downstream partners for its own use (Matthyssens,Vandenbempt and Goubau, 2008). This has led to a product centric business logic in which value is seen to be created when technically functional product or solution is sold and delivered to customer. However, recent research underscores that value is fundamentally derived and determined only in use - the integration and application of resources in a specific context (Vargo, Maglio and Akaka, 2008). With current practices, lack of appropriate information about how to use products during its life-cycle from production to delivery, assembly and maintenance, lead to waste of resources and decreased overall value.

NEED TO DESIGN FOR LIFECYCLE/OPTIMISE TOTAL COST OF OWNERSHIP

Most decisions at the design stage are largely made in isolation from life-cycle aspects through local optimization (Reed, 2009). Some of the reasons behind this include managerial and technological limitations (Koskela, 2007). Global life-cycle optimization either for cost, building performance or user experience requires different organizational structures, as information from all domains are typically needed for making accurate life-cycle assessments (Putnam, 1985; Forgues and Koskela, 2008). Design is based on direct costs, at best on short-term profitability. Even when the lifecycle performance of a building or building subsystem is modeled, an unknown gap between potential and actual performance remains in the absence of tools and methodologies to spot opportunities.

The results of these information gaps are that costs are higher and performance lower than would be possible (Clark, 1991). This represents a significant waste of resources in design and construction and ongoing derision of value in use and operations. In the presence of the information gaps the service providers and solution developers remain unable to systematically improve performance of buildings in use or improve the design of solutions based on evidence (Reed, 2009).

WHAT DOES THIS RESEARCH PROPOSE

The central tenet of the intelligent product vision is to either embed or link contextual product and process related information, which needs to be communicated to actors operating on them across the supply chain, within the products themselves. With this, the products “flow” across the lifecycle “demanding” actions to be performed on them and providing necessary information needed to do so. The products collect information about their performance, either automatically through sensors or qualitative feedback from users, which can then be used to analyse its performance in its given contextual space. The basic building blocks and the role they play are provided in this section. These building blocks consist of technological components in BIM, IoT (Internet of Things) based communication systems, Agents and process and people related enabler in Lean Construction.

BUILDING INFORMATION MODELLING

Building Information Modelling (BIM) plays a central role in this concept. Products start their life as virtual representations in the BIM system and are assigned an URI (Uniform Resource Identifier, used to locate and link information across web) (or recognised with an existing one) from their inception in BIM, and also when in physical form (i.e. when it is purchased/assembled/constructed) and is associated with the product for its lifecycle. For example, by selecting a product in BIM from a manufacturer’s catalogue will link all the product specification, installation and tolerance related information that is available from the manufacturer’s system. This information is not integrated or input in the BIM model but only linked to it using the URI of the product. This way the model remains “light” and yet enriched with information. Although BIM systems may not be needed to input the information or store in the database/model, they should have appropriate user interfaces in order for users to interact with the information and visualise it.

INTERNET OF THINGS (IOT)

Like BIM, IoT also plays a key role in the proposed concept, as it provides the infrastructure where each individual product or indeed any object, organisation or entity within a project can be assigned a URI and information attached to it, which can then be accessed through appropriate interfaces. The IoT concept is nowadays mainly used for describing a network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment. The IoT encompasses hardware (the things themselves), embedded software, communications services and information services associated with the things. In practice, the IoT concept also includes data systems that contain information about those physical objects, such as design and manufacturing documents, service records etc.

STANDARDS FOR IOT COMMUNICATION

A communication framework for the IoT has been developed by the IoT Work Group of The Open Group (formerly called Quantum Lifecycle Messaging: QLM) that enables system-system, system-human and human-system communication, and also plays a key role in the concept. The communication standard has a potential to address the construction project lifecycle with BoL (Beginning of Life), MoL (Middle of Life) and EoL (End of Life) stages as depicted in Figure 3. Communication is at a centre stage in construction as the information has to be delivered to the right actor at the right time and in addition information has to be captured at the right moment (also in the field or on the move when concerned with logistics). The Open Group standards enable such a dynamic exchange of information to support the product lifecycle at each stage as shown in Figure 3 through the O-MI cloud.

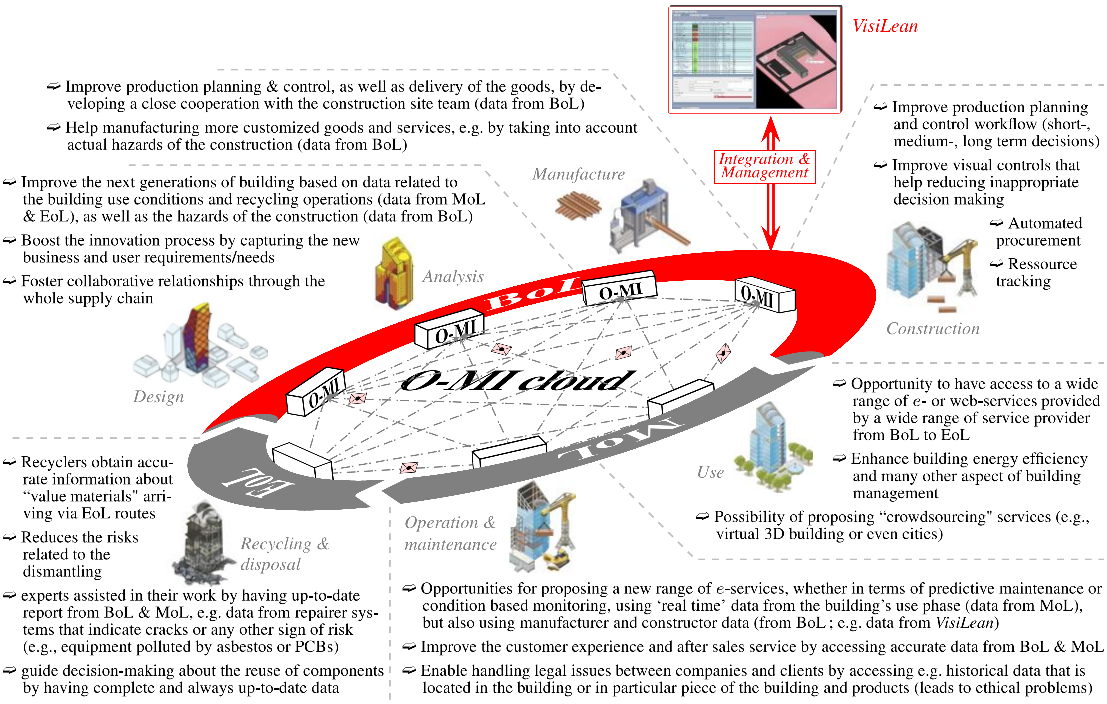

Figure 3: Open Group IoT Standards across the Project Lifecycle.

AGENTS

The notion of virtual enterprise (Aerts, Szirbik and Goossenaerts, 2002) describes a setting where supply chains become increasingly dynamic and network-like. Agents have been used for representing the participants of the supply chain, e.g. order acquisition agents, logistics agents, transportation agents, scheduling agents etc.(Fox, Barbuceanu and Teigen, 2000). The purpose of the agent architecture is typically to model, simulate and analyze supply chain operations in order to achieve better control of them (Scholz-Reiter and Höhns, 2003). Product items can have associated agents (Holmström, et al., 2002; Kärkkäinen, et al., 2003), which can greatly simplify access to product information. It can also simplify updating product information in tracking applications, for instance. In a multi-company setting, agents usually communicate over Internet connections.

Internet has become nearly ubiquitous for companies in all developed countries, making point-to-point connections obsolete. So if Internet access is available, there is no point in moving all product data along with the physical product. A challenge is that the link should be valid for the whole product life cycle. The information should also be constantly available (24/7).

As shown in Figure 4, in the agent model, information is fetched and/or updated only when needed. Information access can be split into two main functions, namely:

1. Accessing product data. Typical product data that needs to be accessed are user instructions, maintenance records, assembly instructions etc.
2. Updating product data. Typical updates concern tracking of shipments, maintenance records, status monitoring of machines etc.

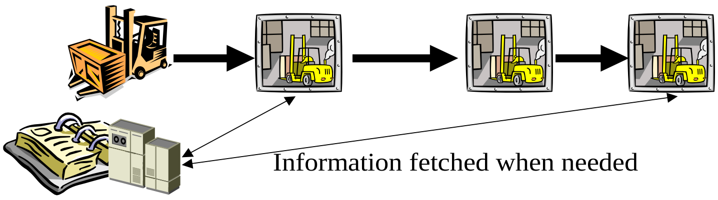

Figure 4: The "agent model" for real-time access to product information.

MULTI-AGENT SYSTEM AND INTELLIGENT PRODUCTS

Multi-agent systems add another layer to agent intelligence, because in multi-agent systems there is an opportunity to exploit collective intelligence, which is greater than the sum of the parts. In such a scenario it is possible to achieve fairly complex set of tasks using simpler agents, because the complexity is achieved through the interaction between the agents and the knowledge distributed across the different agents.

The ability to deal with complex tasks with fairly simple agents is particularly relevant to the proposed view of intelligent products. While construction projects and the information flow in such projects are known to be complex, the control logic and sub-tasks can be broken down to simpler rules at individual product levels. Thus, the rules and logic encoded within each product can be simple, but the ability for these products to interact with each other, and the human agents around them, will allow complex set to actions and activities to be realized within the construction projects.

LEAN CONSTRUCTION

Lean construction plays a central role in the intelligent products concept through the application of "pull" production concept and also through alignment of value across the supply chain. The underlying motivation behind intelligent products concept is to maximize value generation (or minimize value loss) and reduction of waste due at all lifecycle stages – the central tenets of lean.

While the concept proposes to automate several scheduling and control functions, it still relies on collaboration between project team that could be achieved by the Last Planner System. In production management the vision support "just in time" logistics and pull production by automatically scheduling deliveries and requesting next task action based on current status. Also, it aims to support Lean Design techniques such as Target Value Design and Choosing By Advantages by providing real-life data about components/previous designs when designing for new projects.

POTENTIAL SCENARIOS

JUST-IN-TIME LOGISTICS BASED ON PRODUCTION STATUS

Resource management on construction sites is one of the most important areas from production management perspective (Koskela, 2000; Ballard, et al., 2002). Through intelligent products, the individual components and assemblies will have the sequence and control logic of the production embedded or attached with them already from the design phase. Through multi agents and IoT framework and a pull based production system, the products will themselves “know” when the next operation that needs to be performed on them and the related schedule. Hence, a product would “call” for delivery from a manufacturer or a supplier when it is ready to be shipped to the site. Once on site, the product would provide information about its location and “call” the worker when it is ready to be installed. Such production logic would be extended to the lifecycle of the product and can even include design and operations.

DESIGN LIFECYCLE ANALYSIS

The concept of intelligent products can become resourceful for designers and engineers building new structures. Spaces are needed for fulfilling client’s functional requirements and if one considers space also as a product, even though abstract, then feedback loop from previously built buildings and their actual spatial performance can facilitate building workspace planning (Pennanen, 2004). Based on programming, performance requirements can be assigned to these spaces, e.g. what should be the level of humidity, temperature, air volume exchange, safety etc. What is fundamentally important here, is how different elements become sub-systems, and systems as a whole building. Therefore, intelligent products can support the synthetic integration of basic entities into greater wholes for meeting client functional needs and performance requirements. Building information modelling combined with lean design practices such as target costing, target value design, choosing by advantages can benefit from intelligent products as it helps to maintain the whole life-cycle view of designing product either in building programming, developing a conceptual design or choosing proper physical structures and products.

LEAN MAINTENANCE

The operations and maintenance phase of a built facility accounts for the major share of project cost and resource consumption, hence it can have a significant impact on the realized project value. One of the key characteristics of the maintenance related issues is their time criticality and potential disruption of routine. Typical maintenance issues can disrupt existing value-delivering activities that are already running smoothly. With effective information management such disruptions can not only be reduced, but potentially prevented. Thus, among other approaches, maintenance response time and preventive maintenance are seen as two important pathways to technology-enabled lean maintenance. While such trends are already visible in current building automation systems, the intelligent product approach extends the possibilities to a new dimension. In the new paradigm, the various systems and sub-systems can also be envisioned as agents that interact through instant messaging, self-diagnose and self-organize, reducing the information delay, reducing the layers of information exchange, and prevent potential waste that may occur due to cascading damages that could result from delayed maintenance of a critical sub-system.

DISCUSSION AND CONCLUSION

There are significant problems with production and supply chain management, information management and design management within the construction lifecycle. There have been attempts to provide solutions to individual areas including lean construction techniques of design management, supply chain alignment and production management and control. However, there is not yet a unified vision to address these problems across the entire lifecycle. The proposed vision attempts to tackle these problems through a combination of process-product-technology solutions. It is an ambitious vision, where most building blocks have individually proven their merit, however it is hypothesized that when combined their collective benefits will be much more significant. It is also anticipated that there will be many obstacles in realizing this vision, and it is a medium to long-term vision that has a potential to change the built environment lifecycle.

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CONSTRUCTIBLE BIM ELEMENTS –A ROOT CAUSE ANALYSIS OF WORK PLAN FAILURES

Laurie Spitler[1], Tom Feliz[2], Nathan Wood[3], Rafael Sacks[4]

ABSTRACT

The project Building Information Model (BIM), made up of component trade models, can be used to coordinate and sequence building elements prior to construction. The model should serve as a surrogate for prototyping the actual construction process and can also be used to implement the lean practice of filtering work for constraints prior to assigning work. The term 'constructible BIM element', referring to an element that can be built exactly as it is modeled, is defined to focus on the use of the model for constraint removal and visual planning. Using an in-depth case study, incomplete assignments from Weekly Work Plans were identified and their root causes were mapped onto their associated BIM objects. This spatial analysis makes explicit and begins to quantify the connection between constructability of BIM elements and the variability of work execution in the field. Learning from the underlying patterns, the authors propose process changes for teams to more effectively identify constructability issues in BIM models, and thus leverage the BIM process to improve the reliability of field work planning.

KEYWORDS

Building information modeling (BIM),constructability, root cause analysis, weekly work plan

INTRODUCTION

Removal of constraints to reduce variability of production rates in a system is central to the concept of flow in construction. The Last Planner process removes constraints on activities through the make ready process. Missed tasks indicate that constraints were not removed. Through tracking missed tasks, the Weekly Work Plan serves as a barometer of flow on the project. To construction contractors, a Building Information Model is a virtual model of a project created prior to and during construction to facilitate understanding of how to design, plan, build and maintain the project.BIM is used to coordinate elements, visualize upcoming tasks and communicate information. Deviations between the digital information in the model and the physical assembly

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indicate that the digital elements or their context were not modeled with sufficient detail to execute in construction. If such deviations could be identified in advance, as part of the make-ready process, fewer immature tasks would be assigned.

To this end, the authors introduce and define the notion of a ‘constructible’ BIM element and explore the typologies of digital elements that are not constructible. The connections between missed tasks and the constructability of the BIM were reviewed using root cause analysis in a case study. A process for teams to proactively identify constructability issues in BIM and thus to leverage the BIM process to improve the reliability of field work planning is recommended.

LITERATURE REVIEW

The importance of flow on construction projects has been thoroughly established by Koskela (2000). Ballard (2000) asserts that the lookahead process has “the job of work flow control”. By identifying constraints through planning assignments 3-6 weeks out, teams begin to “make work ready” in the construction process (Ballard, 2000). In the same way, teams use the BIM to identify various constraints that may arise in the design and planning process, primarily by means of clash detection (Eastman, et al., 2011). Sacks, et al. (2010) proposed a framework for research of interconnections and synergies between BIM functionalities and Lean Principles. The framework shows that the Lean Principles with the highest number of interactions with BIM Functionalities are (A) getting quality right the first time (reduce product variability), (B) focus on improving upstream flow variability and (C) reduce production cycle variations.

Tommelein and Gholami (2012) investigated the root causes of clashes in BIM models and concluded unequivocally that clash detection relates directly to removing waste and improving flow, contributing to buildability. Bhatla and Leite (2012) presented the case for the use of BIM to support the Last Planner System™ (LPS) process for construction, hypothesizing that 4D visualization will lead to a better understanding of progress and that the collaboration involved in clash detection will reveal constraints. In addition, Khanzode (2010) demonstrated that the use of the LPS to set objectives and manage the process of BIM coordination leads to an increased rate of prefabrication and a reduction of construction RFIs. Together, these studies demonstrate an interesting reciprocity between BIM and LPS.

Egan (1998) claims that too much time is spent in construction on site trying to make design work in practice. This results from the separation of design from the rest of the project. Sacks, Treckmann and Rozenfeld (2009) expand on the silo mentalities (Jones and Saad, 2003) that obstruct sharing of information across project phases and teams. BIM coupled with Lean helps foster a collaborative culture in which personnel build on prior knowledge, leading to less information being lost from phase to phase of the project. BIM facilitates transfer of information and knowledge to the right people at the right time in the right place throughout the supply chain.

CONSTRUCTIBLE MODEL ELEMENTS

The information in the coordinated BIM should aid the customers of the BIM, the last planners who install the work, in field planning and implementation. In the make ready process, BIM can be used to verify construction flows such as design, components, space, and connecting works (Koskela, 2000). In short, to be of value as a prototype, the BIM must be constructible as modeled. To be constructible, each element must be modeled with thought towards installation sequence and the characteristics of the physical fabrication. A BIM element may be considered constructible if four conditions of constructability are met:

- The form and location of the digital representation and physical fabrication meet the conditions of satisfaction.
- The form (geometry) of the digital representation accurately represents that of the physical fabrication.
- The paths through which the fabrications must move to their installation locations must be unobstructed. The sequence of installation as modelled must be free of time-space conflicts (which can be represented and checked using 4D (Akinci and Fischer, 1998).
- The physical fabrication can be placed in the location of the digital representation. The modeled assemblies surrounding the digital element must accurately represent that of the existing condition of the building.

If these conditions are not met the element is considered not constructible and the model element will not be a reliable tool in the make-ready process. In the process of realizing prototypical BIM elements as fabricated building objects in the field, there are two major hand-offs of information. The first is when the element is released for fabrication. As shown in Figure 1, information from the model can be directly fed into the machine fabricating the physical element (automated fabrication);the fabrication process can use information represented in shop drawings produced directly from the model (direct fabrication); or a more circuitous path is followed, typified by fabrication independent from the model and the use of the model as a reference (indirect fabrication).

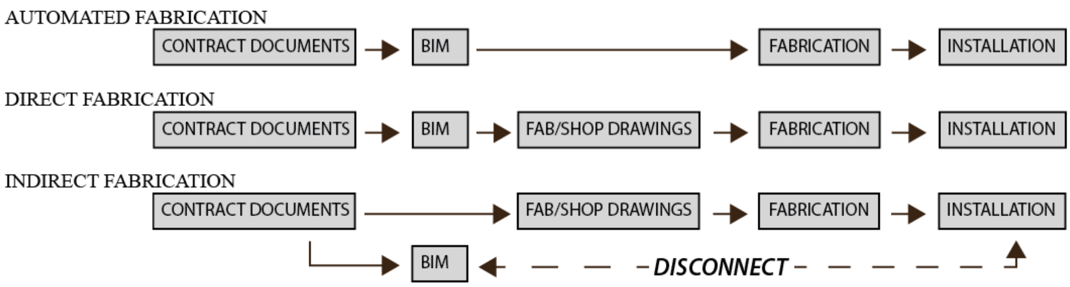

Figure 1: Automated, direct or indirect fabrication.

The second information hand off is between the model and the field. If the workers installing the physical fabrication do not have the correct information, the chances of deviation from the model are greater. It should be noted that this relationship is reciprocal. If installation needs are not communicated to the modelers, the chances of the digital elements being modeled in an unconstructible location or form are greater. In the field, the sequence of work installation is critical in determining outcomes. A fabrication often cannot be installed in the same location as the BIM due to another fabrication occupying that location. If the primary physical fabrication cannot be placed due to an adjacent fabrication, the analysis must be expanded to determine the installation logic of the secondary fabrication.

Thus by considering the technical limitations of the model, transfer of information, conditions of satisfaction, and the effect of adjacent physical fabrications, one can determine the root cause of the unconstructible element. Figure 2 shows a flow chart for this procedure. It should be noted that in certain conditions, multiple root causes will be present.

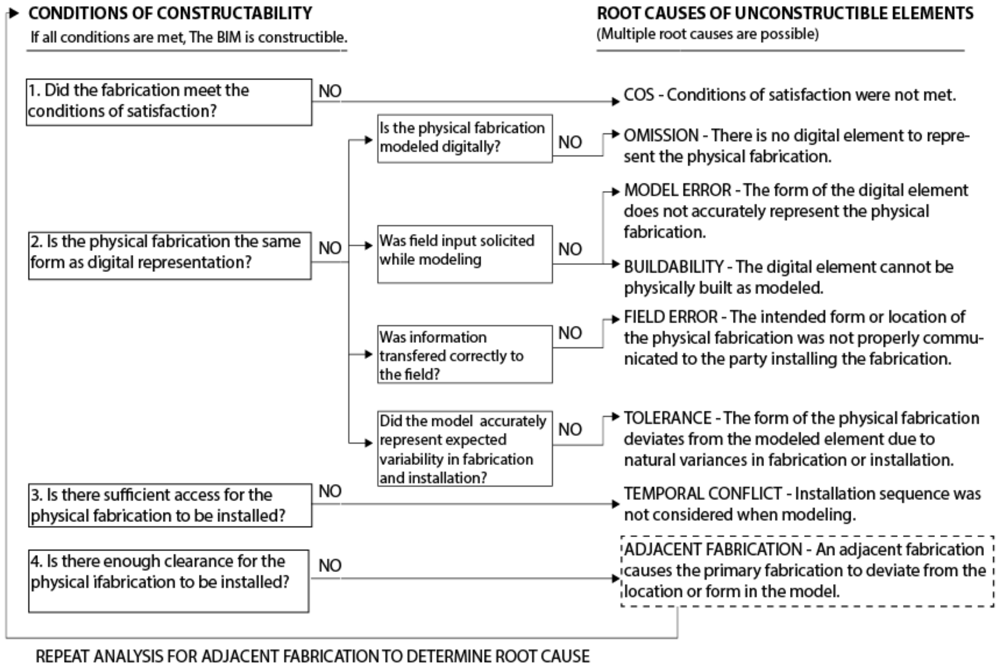

Figure 2: Model Constructability Analysis Flow Chart

METHOD

A core and shell downtown high-rise office building, currently under construction in San Francisco, was used as a case study for root cause analysis of constructability failures and identification of their relationships to elements in BIM. An industry standard BIM execution plan was implemented on this project. Steel, mechanical, electrical, plumbing, fire protection and framing trades contributed to the model. Clash detection was performed using Navisworks and coordination meetings were held for clash resolution. The architect’s model was used as a proxy for trades who did not contribute models. The extent of BIM element detail and level of engagement by each trade is shown using the BIM Participation Matrix (Spitler, 2014) in Figure 3.

The Weekly Work Plan was used to track commitments and Planned Percent Complete results were recorded by trade. Commitments were tracked by trade contractor, description of work, and location. If a commitment failed, a reason code was recorded. Fifty two weekly work plans were analysed. Missed tasks from the weekly work plan were tracked by area, time, contractor, and reason code (see Figure 4). The density of the fill in the figure correlates with the number of missed tasks. These missed tasks were then spatially mapped to BIM elements to determine if the root cause of the task failure could be traced to an unconstructible BIM element. All missed tasks were plotted on a pivot table with location along the y axis and time along the x axis. Using the sorting filters assigned to each task, patterns, or clusters, of missed tasks were identified. Further analysis of these clusters was performed to determine the root cause of these systemic failures.

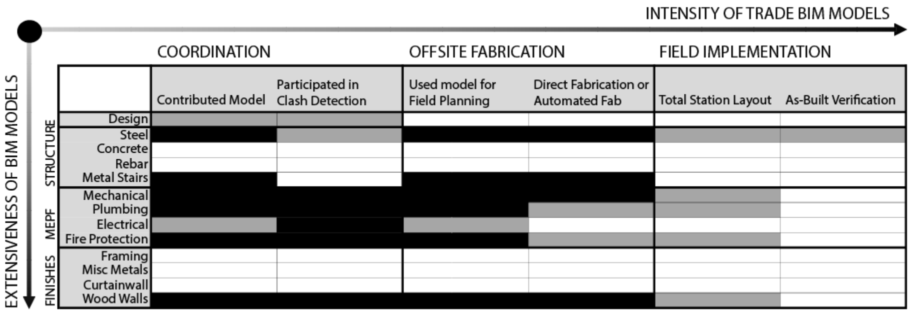

Figure 3: Case Study BIM Participation Matrix (refined from Spitler, 2014).

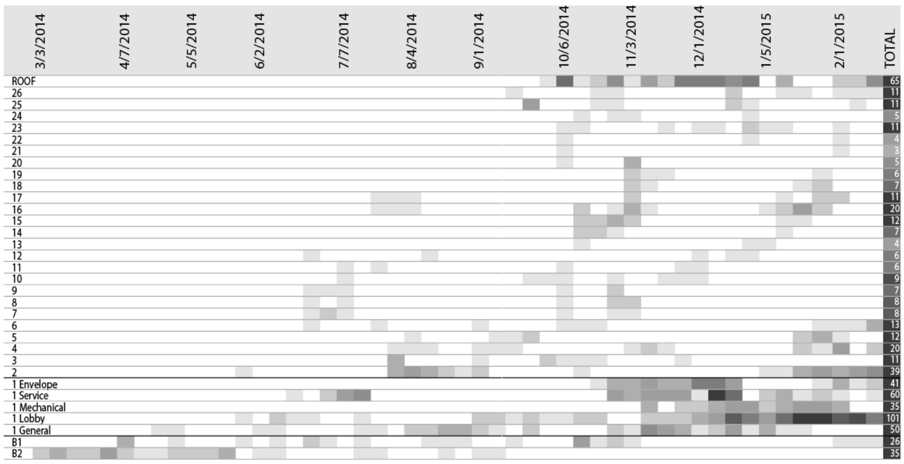

Figure 4: Missed activities sorted by location and schedule (darkness of the squares represents the density of missed tasks)

In this analysis, potential biases in data must be considered. While the WWP tracking on the case study was comprehensive and detailed, the data tracked in the WWP is subjectively entered by the project team. Work that is not essential to meeting that deadline may not be tracked accurately in the WWP. Rework and delayed areas may not be distinguishable from base work. In some isolated cases, the root causes cannot be determined with complete confidence because only eight reason codes were assigned. However, despite these limitations, given the amount of data, this case study is considered to be sufficiently rich and accurate to support identification of general trends and patterns.

RESULTS

The project planning record included 2,228 tasks overall with a total planned percent complete of 71%. Of the 637 missed tasks, 24% can be attributed to factors unrelated to the BIM such as material, labor, or weather. At least 23% (146 tasks) have root causes that are represented in the BIM. The inability to identify the root causes in the BIM of the remaining 53% of missed tasks is due to the fact that some 90% of their work scope was not modeled at all. Two types of patterns were identified in the data:

trade clusters and location clusters. Of the 146 missed tasks whose root cause was visible in BIM, 83% could be attributed to one of these two types.

TRADE CLUSTERS

Trade clusters are characterized by having a root cause that repeatedly causes task failure across multiple locations. Seven trade clusters were identified and numbered in Figure 5(a) and can be seen to repeat on several floors. The root cause of three of these is visible as unconstructible elements in the BIM model. Clusters4&6in the figure represent a repeated task failure due to wall detail that did not match the field condition due to a model error. The model error, in this case, is in the handoff between the architects' design and its digital representation in BIM by the drywall subcontractor. When the shaft wall layout was changed by the architect, the requirements did not flow down to the drywall detailer to update the model. Had this been done, the drywall detailer would have noticed a new detail was required. Identifying this constructability issue earlier in BIM could have allowed greater flexibility of alternatives to choose from and ample time to adjust the plan for impact in flow. Instead, the issue was identified by the last planner in the field. The new detail required steps that had not been factored in the look ahead plan. This task failure accounted for over 10% of missed tasks on the project in the period of study.

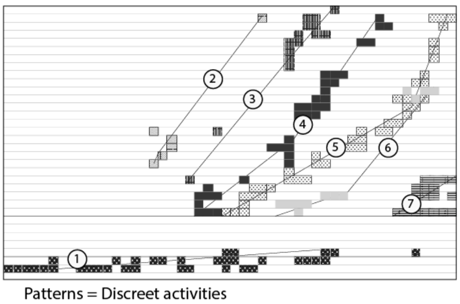

Figure 5(a): Trade Clusters

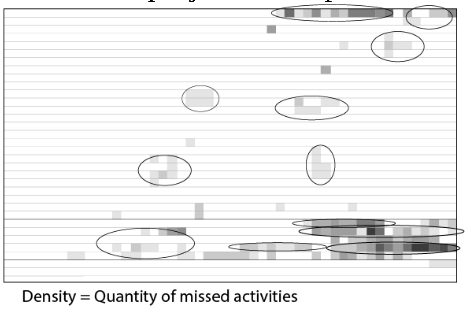

Figure 5(b): Location Clusters

Cluster 7 represents the restroom build. The location of walls with regards to code required clearance dimensions was not fully worked out in the model. The model was not used for layout in the field, resulting in rework in plumbing to match the new location of the walls. Of the BIM constructability issues in this cluster, 87% were information transfer issues (Root causes = field errors, model errors, and buildability).

LOCATION CLUSTERS

The second type, the location cluster, is characterized by multiple trades in a concentrated location and time period (see Figure 5b). The high interdependency between trades causes small errors by earlier trades to compound with subsequent trades. It logically follows, and this is shown in the data, that these clusters occur where the design calls for a high level of interaction between trades. Of the twelve clusters identified in the data, nine occur in areas which have a high degree of interaction between trades. Nineteen percent of the missed tasks had root causes visible as unconstructible elements in the BIM.

One such area occurred at the generator exhaust riser (see Figure 6). Table 1 lists the scopes involved, sequence of installation, and root cause(s) identified by the model constructability flow chart.

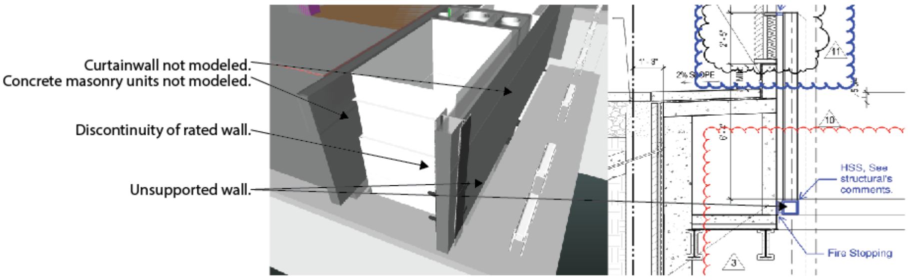

Figure 6: Constructability issues at Generator Duct Riser

Table 1: BIM Constructability analysis - Generator riser location cluster

Scope of Work Sorted by Installation Sequence	Modeled	Conditions of Constructability (See Figure 2) 1. Conditions of satisfaction	2. Accurate Form?	3. Access?	4. Clearance	Missed Tasks	Reason
1.Concrete Slab	Yes	Yes	No	Yes	Yes	0	Omission
2.Concrete Block Wall	No	Yes	No	Yes	No	0	Omission
3.Curtain Wall	No	Yes	No	Yes	No	5	Omission
4.Drywall Framing	Yes	No	Yes	Yes	No	16	Buildability, model error
5.HVAC Ductwork	Yes	Yes	Yes	Yes	Yes	0	Adjacent element

The result of the root cause analysis, as is typical with location clusters, is multiple failures. The omission of the structural trades caused a discontinuous rating issue to not be identified until work was in place. The model error (placing wall in an incorrect location) caused the team to miss additional support needed to install walls. Reliable flow depends on a level of confidence that the adjacent trades have installed their work per BIM. Indeed, the lack of a model for concrete and CMU block negatively impacted subsequent trades' installation, but not the structural installation. Basic modelling of structure and curtain wall scopes in conjunction with visual planning would have allowed the last planners to visualize and mitigate issues. This failure cluster accounted for over 6% of missed tasks in the entire project in the period of study and caused delay in a critical area of the project.

DISCUSSION

The general trends shown in the project level analysis are illustrative of the approach of contractors to design, fabrication and installation of product. When plotted in order of sequence (figure 7), trends emerge. First, it can be seen that the rate of missed tasks increases in later trades. This is intuitive, as trades who install first only have to coordinate within their scope to have an on-schedule installation. Trades who follow have to navigate work in place as well as internal coordination when installing work. When the team is considering who should contribute to the BIM, the value of the contribution to subsequent trades should be considered.

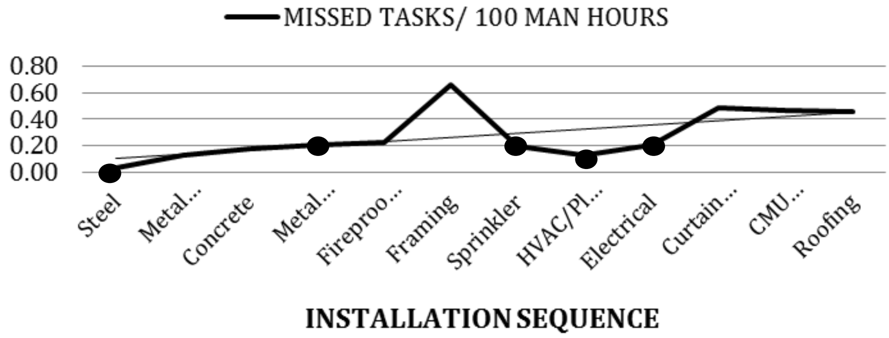

Figure 7: Missed Task Rate by Trade and Sequence

Second, it can be observed that trades who directly fabricate from the model have fewer missed tasks. This can be attributed to the amount of preplanning achieved through coordination and on the confidence and validation that the digital representation matched the physical. Confidence is gained when direct digital fabrication and placement is utilized. For example, MEP scopes can achieve the highest level of confidence due to the process of direct fabrication, robotic total station layout, and installation of the prefabricated pieces. When the coordination and planning is complete prior to construction, installation equates to assembling a kit of parts rather than figuring out atypical details in the field.

RECOMMENDATIONS

The data show that the majority of missed activities are not random, but predictable and clustered by trade or area. It follows that the most efficient mitigation of these issues requires a process solution. Addressing constructability and installation sequence in BIM coordination and execution in a rigorous way would remove constraints that could otherwise be missed until installation. The benefits would include reduced schedule variability, smoother workflow and increased productivity.

With hindsight, it is simple to identify areas of the models that should have been better resolved. The question becomes how teams can deploy BIM more effectively to resolve constructability issues prior to construction. Traditional BIM execution plans rely on prescriptively defining Level of Development by trade and applying clash detection, essentially a push approach that does not consider where value lies. Instead, BIM execution should be tailored to the needs of the building and the abilities of the participating trades. On the basis of these conclusions, four recommendations are made to help teams prioritize and focus their BIM efforts:

- **IDENTIFY POTENTIAL CLUSTERS OF UNCONSTRUCTIBLE ELEMENTS.**To identify potential clusters, teams must rely on trade partners to contribute experience on past issues and delays which are applicable to the current project.Areas of the building design that are atypical or new to trade partners and areas that require a high level of coordination between trades should also be considered. Rather than specifying a level of detail by trade alone, the BIM execution plan should define locations (areas) to be modelled to greater detail.
- **CLASSIFY CHARACTERISTICS OF UNCONSTRUCTIBLE ELEMENTS.** Clash detection is simply an algorithm that identifies if an element physically intersects

with other elements. Similarly, it would be desirable to develop BIM functions capable of rigorously identifying the four types of constructability issues identified in Figure 2. For example, as seen in the trade cluster example, buildability and field errors occur at the shaft walls due to the specificity of the detail and the indirect fabrication method of the sub. Abstracting this example, it can be stated that there is a potential for buildability and field errors at elements indirect fabrication method and a precise location. Areas that meet these characteristics, such as edge of slab, walls defined by required clearances, can then be identified and mitigated.

- **REALIZATION METHOD.** How well a model is coordinated becomes irrelevant if it is not built as modeled. Individual trade's BIM to field translation methods should be reviewed and understood so that appropriate 'as-builting' and model verification strategies can be built into the execution plan. To ensure success, trades should be engaged in the planning process to fully realize the extent of participation required.
- **RETURN ON INVESTMENT OF BIM COORDINATION AND TRANSLATION**. Project teams should consider the investments proposed during the early stages to maintain confidence that BIM accurately models reality. Contractors who directly fabricate from BIM are intrinsically motivated to contribute accurate models. Contractors who do not fabricate from BIM are not. Therefore, it is important to align the requirements with the beneficiaries where possible.

While implementing this framework, the importance of having the right people in the room at the right time cannot be overstated. For each area of focus, the team should check in periodically during model development to review the conditions of constructability. In the early phases of the process, the right people to address constructability may be the procurement and management team. Once coordination starts, these questions need to be answered by the field team, the Last Planners. As each predefined point is met, the team's knowledge should effectively transfer downstream and confidence in the constructability of the BIM should increase.

Missed tasks in the weekly work plan indicate that the make ready process was not complete for those tasks. Often, the root causes of those missed tasks can be seen as unconstructible elements in BIM, indicating that the BIM process was not effective in removing constraints. Therefore, the framework proposed above is designed to pull BIM execution directly to the make ready process for construction. By explicitly focusing on areas whose field execution benefits most from BIM, the team will eliminate waste in the BIM process. By implementing coordination processes designed to address all types of constructability and understand translation methods, the team will ensure that the model will be a useful tool for building. Most importantly, using the four conditions of constructability to measure confidence in, and maturity of, the model, the team can ensure that the preconditions of construction tasks have been effectively met with the aid of BIM.

CONCLUSION

This case study demonstrates that the root causes of missed tasks are often visible as constructability issues in the BIM and that the project BIM is a useful medium for the spatial analysis of root causes.The explicit definition of the term 'constructible BIM object' is useful for project teams who leverage BIM for constraint removal. Although the recommendations are based specifically on the analysis of a single case study, the method of analysis in this paper provides a foundation for future research as well as practical metrics to measure the constructability of the BIM in construction practice.

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SITE LOGISTICS PLANNING AND CONTROL USING 4D MODELING: A STUDY IN A LEAN CAR FACTORY BUILDING SITE

Rafaela Bortolini[1], Jeferson Shin-Iti Shigaki[2], and Carlos Torres Formoso[3]

ABSTRACT

A major challenge in most construction projects is the need to coordinate a large number of logistic operations in site installation. Despite the growing use of 4D models for planning and coordinating construction activities, the traditional approach adopted for those models is simply to represent the installation sequence defined in a CPM network, which is limited only to conversion activities, whilst a lean perspective suggests that production should also be seen as a flow. The purpose of this paper is to discuss how to plan and control logistics processes in engineer-to-order prefabricated building systems with the use of 4D BIM modeling. This paper investigates the use of BIM to simulate both value-adding and non value-adding activities, such as waiting, inventory and moving materials, as well as site layout.

An empirical study was developed in an industrial project for a Car Manufacturing Company that is highly advanced in the implementation of lean production. The scope of the research project includes both the simulation of logistic operations and the monitoring of those operations in the construction site. This paper discusses the benefits and limitations of using 4D BIM for planning and controlling logistics operations in construction sites. Moreover, this study highlighted the need to plan and control site logistics processes hierarchically and focus on logistics critical processes.

KEYWORDS

Building information modeling (BIM), logistics, prefabrication, 4D modelling, visual management.

INTRODUCTION

In the context of engineer-to-order prefabricated building systems, the management of construction projects requires a large amount of information and treatment of

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inaccurate data. The degree of uncertainty is high due to environmental factors, design errors, late design changes, lack of information, communication failures, delays in materials delivery and other issues (Hajdasz, 2014). Engineer-to-order (ETO) companies usually supply highly customized products to meet individual customer requirements. According to Hicks, McGovern and Earl (2000), the high level of customization in ETO products may lead to increased costs, higher risks and long lead times. The complexity of product structure makes outsourcing more difficult at the same time the variety of ETO projects implies in the involvement of many different types of supplier relationships. Therefore, logistics planning and control is extremely important to achieve the goals of schedule, cost, quality and safety of ETO building projects. Moreover, empirical observation within an ETO company has indicated to need for a site logistic planning in order to reduce wastes stemming from excessive transportation of material and equipment and also duo to the poor organization of components on-site.

The layout of materials and temporary storage facilities areas needs careful planning to minimize costs and moving resources, and comply with the operational and safety constraints (Said and El-Rayes, 2013). Also, the difficulties imposed by on-site work and the complexity and dynamic nature of construction create the need for effective ways to support construction planning and control (Hajdasz, 2014). In fact, several research studies have suggested the potential use of 4D models in planning the construction site.

Most previous studies on the use of 4D models for construction focused on a specific topic, such as site layout planning (Zhang, Ma and Cheng, 2001); analysis of conflicts related to safety (Zhang and Hu, 2011); automatic generation of work spaces (Akinci, Fischer and Kunz, 1998); producing visual logistics and resource schedules (Chau, Anson and Zhang, 2004), and analysing the movement of equipment onsite (Olearczyk, Al-Hussein and Bouferguène, 2014). Despite the contributions of those research studies, none of them investigated the interactions between production planning and logistics planning, and how to implement logistics plans in an organizational context. Moreover, most studies do not address details of logistics operations and material inventory. In fact, most studies on 4D models simply a translation of the output of a CPM network that contains only transformation activities, so criticized by the Lean Construction Community. It implies that the so called flow activities are being neglected once more.

This paper investigates the use of 4D BIM modeling to plan and control logistical operations on site for ETO prefabricated building systems, including site layout, main unloading operations, inventories, and critical site assembly operations. This research study is based on an empirical study carried out in and industrial development is placed in a construction project, which the has as a client a car manufacturing company that was very demanding with their suppliers in terms of implementing some core lean production ideas. This investigation was developed in partnership with a steel fabricator company (Company A), but also had a strong interaction with representatives of the client organization, since these were actively involved in the implementation of some innovations in the site assembly process.

LITERATURE REVIEW

LOGISTICS PLANNING AND CONTROL AND 4D MODELING

Site logistics planning and control involves site layout planning activities (Said and El-Rayes, 2013), which imply the definition of the space needed for the movement of materials (Tommelein and Zouein, 1993), and decisions about what to do in conflicts situation of space and time (Akinci, Fischer and Zabelle, 1998), and the size, shape and location of fixed and temporary facilities, as well as vehicle routes necessary for the development of operations, during each phase of the site. In addition, logistics planning and control should aim to eliminate or reduce material transportation operations, and to avoid congestion of flows in the construction site (Tommelein and Zouein, 1993) by controlling operations involved in the unloading of materials (Agapiou, et al., 1998). Agapiou, et al. (1998) state that logistics planning can have a highly positive impact on the productivity of construction operations.

The aim of 4D BIM models in production planning is provide a virtual environment for simulating and viewing production processes and operations (Davies and Harty, 2013).Those models offer the opportunity of identifying resource conflicts in time, with the aim of improving efficiency and safety, and improving the flow through the identification of bottlenecks (Davies and Harty, 2013). For instance, Olearczyk, Al-Hussein and Bouferguène (2014) investigated the use of 4D models to analyse the vehicles trajectory on construction sites. Akinci, Fischer and Kunz (2002) explored the use of 4D models to detect possible conflicts of space and time. Wang, et al. (2014) investigated the modeling construction operations and analysis of the materials inventory, which in this research is called critical operations. Also, some research studies used 4D models for planning and testing construction sequence alternatives (Chau, Anson and Zhang, 2004) and predict potential logistical problems (Hartmann, Gao and Fischer, 2008).

RESEARCH METHOD

Designed Science Research, also known as Constructive Research was the methodological approach adopted in this investigation. According to Kasanen, Lukka and Siitonen (1993), constructive research aims to develop innovative solutions that solve practical problems and at the same time allow a theoretical contribution. Figure 1 presents schematically the research design, which was divided into the following stages: (a) a literature review; (b) understanding the problem; (c) development phase, based on an empirical study; (d) analysis and reflection phase. This paper reports some of the results of broader research project, which aimed to devise a logistics planning and control model to be detailed in a further publication.

As in most design science research projects, the development of the solution involved several cycles of planning, execution, data collection, and analysis. At each cycle, the plans were revised and detailed, based on feedback from site operations and also due to additional demands of information by site managers. The main sources of evidence are presented in Table 1.

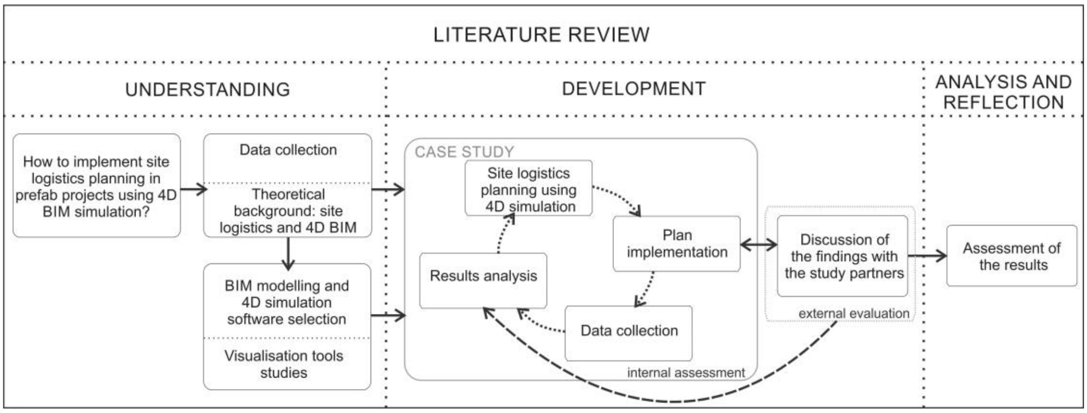

Figure 1: Research design

Table 1: Sources of evidence

Goals	Sources of evidence
Understand the site characteristics, the construction and logistics process and possible challenges on site	Interviews with both site engineer and project coordinator Site visit to identify its main features and implications for site planning
Understand the client requirements	One hour meeting with the client and the site engineer to discuss the first version of the proposed logistics plan
Logistics planning	4 one-hour meetings with the site engineer and a client representative to define the site layout and a solution for logistics operations
Implementation of the logistics plan	Participation in 4 planning and control meetings involving company managers and client representatives, with an average duration of 30 minutes, to discuss the construction progress
Assessment of the implementation	15 site visits focused in analysing the proposed logistics plan

In terms of software, this study has used ArchiCAD® to model the building product, using 2D drawings provided by the design team as a starting point. Synchro Pro® was used to develop 4D models. It was initially developed with its components at scheme design level of development, considering that for this macro site planning it did not require a very high level of detail. The model was divided into nine building stages, which were identified with the same colours of labels made for the components identification. It was used to support collaborative decision-making related to logistic planning.

EMPIRICAL STUDY

Company A is a steel fabricator that design, fabricates and assembly on site steel structures mostly for industrial buildings, warehouses, supermarkets, and high rise buildings. It is considered the largest steel structure fabricator in Brazil, with more than 2000 employees, 3 manufacturing plants, and around 200 simultaneous contracts.

Short delivery times and design flexibility are the main competitive advantages of this company.

The development process of the company's product begins with the division of the building into stages with the aim of reducing the batch size. The separation in stages also helps to achieve similar production batches, which should make it easier the detection of errors, as well to establish a stable pace of work. Each stage of the project is divided into sub stages, which are assembly units that can be erected independently.

Company A did not used to perform systematically layout planning and logistics operations studies. In fact, the company did not have standard operations for the unloading of components on site. Therefore, there were several problems in site logistics, such as inadequate location of inventories, the mixing of components from different stages, and time consuming transportation operations. This was particularly common when the logistics department mixed components from different stages in the same load, with the aim of minimizing freight costs.

The project for this empirical study was suggested by Company A, because it was considered as an opportunity to implement improvements in the company's logistics processes due to the fact that the client organization was very demanding in terms of schedule, safety and organization of the construction site. For that reason, Company A decided to implement several improvements in logistics with the aim of improving the performance of the site assembly process.

The project consisted of the assembly of steel components for a 20 thousand square meter single floor industrial building, including steel beams, spatial trusses, sheet metal cladding, sheet metal roofing.

One of the main challenges for the logistics planning in this project was to not mix sub stage components on site. There was a relative large storage area for the projects, due to the fact that the client had an additional area for future expansion of the plant. However, this area had to be shared with preassembly operations without compromising safety and productivity as a well as avoiding conflicting flows with other suppliers.

RESULTS

Company A decided not only to implement logistics planning and control but also to introduce some visual management practices on site. One of the initial decisions regarding visual management was to adopt colour labels to identify the component batches for each stage. In addition, all loads for that project were planned at a very detailed level, based on weight and size constraints. The main assumption made in developing those plans was that each load should only contain components of the same building stage. Furthermore, the components distribution in each load should be positioned in the best possible way for the assembly sequence. Meetings were held to define the loads with the participation of representatives from the logistics department and the site engineer. The loads were delivered according to the assembly sequence defined by the assembly on site.

For the development of the logistic plans, 5 meetings with the participation of site engineers, project coordinator and client were held. In those meetings, 4D simulations were used to refine the sequence of stages, and to define the positioning of storage areas, vehicle routes and pedestrian routes (Figure 2). The storage location was designed as close to the assembling area as possible, to reduce unnecessary transportation activities, and increase productivity.

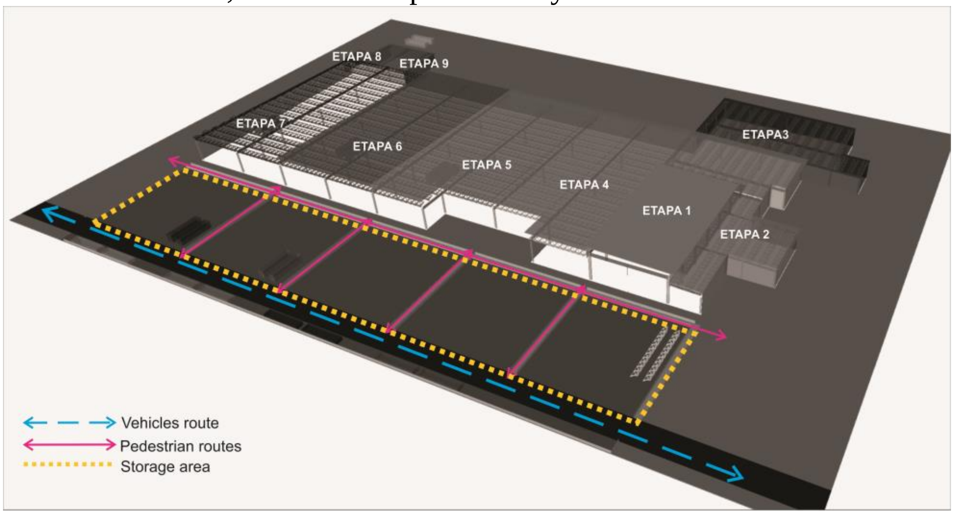

Figure 2: Batch sequencing definition

A line of balance (LOB) was used to generate a long term plan. The LOB was useful to explore alternative execution sequences in combination to the 4D model (Figure 3). Each planned activity occupied a workspace in the construction site and a material storage area. The site layout was divided into bays to prevent mixing of materials and to seek better organization of inventories. Simulation included the indication of pre-assembled trusses areas and logistics processes.

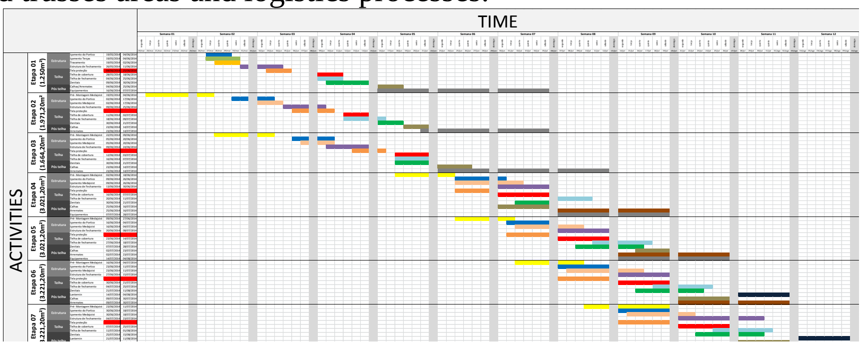

Figure 3: Line of Balance

The importance of client engagement in this work became evident with a change request for the product design. As the Company A seeks maximum reduction in the use of steel for cost reasons, their solutions usually provide a wide variety of components. This variety of parts occurs in the primary structure (beams, frames) and also in the secondary structure (space trusses). Due to customer request for a leaner work, product design was modified in order to decrease to less than a half the number of different space trusses (50 types to 17 types). This action resulted in an increase in the total weight of the project. By contrast, it made simple handling the components and the assembly process, by decreasing the variety of products to be assembled.

The logistic plan developed with the 4D model was implemented on site with the support of visual devices. They were made with screenshots taken from the 4D model in correspondence to time flow. One of the boards that were produced had one screenshot of the building and inventories per week (Figure 4). These boards aim to facilitate the exchange of information in the construction site, being used by different stakeholders including the site engineer, client representatives, and assembling subcontractors. That visual board were used to monitor the assembly process and deviations in inventories.

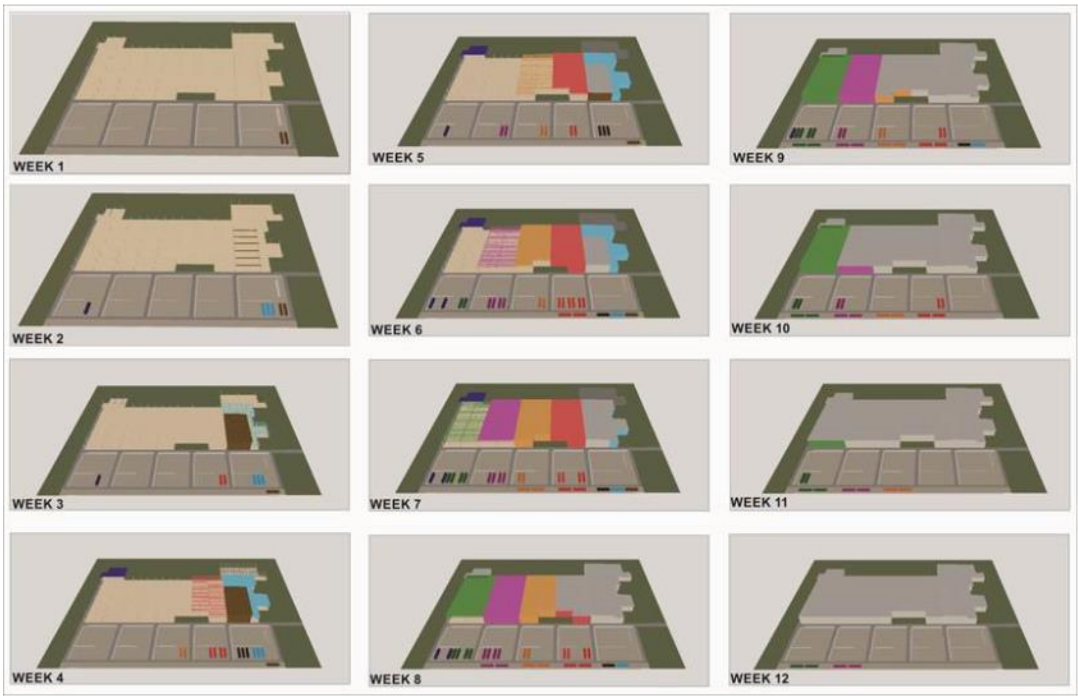

Figure 4: Visual device produced from screenshots of a 4D model

Different visual devices were placed near the assembly area, and in both Company A and client's site offices (Figure 5). Direct observation indicated that the boards were useful to support discussions about production plans and layout.

The implementation process had a control phase about the planned logistics activities. The control phase included the analyses of component unloading operations on site, access routes and pedestrian routes. This control was important to identify the causes of deviations and, when necessary, to revise or detail the logistics plans.

Figure 5: Visual management in the construction site

One critical process was chosen to be planned at a fine level of detail, with the aim of improving productivity in site assembly. The pre-assembly and the lifting of space trusses were the process chosen by Company A. The stage 6 of the building was selected due to the fact that the previous stages were in process and they could be used as a source of data to produce the 4D model.

Firstly, the existing schedule for the pre-assembly activities was analysed. That plan was problematic since a large amount of work in progress was going to be created. Then, the study was conducted with the aim of improving the logistic plan for this particular process. A specific BIM model was developed to a higher level of development, modelling the space truss components at a fine level of development. The storage area and the assembling area were also modelled, and the schedule of the activities involved was analysed in the 4D model. The simulation highlighted the possibility to configure a more continuous process with a minimal inventory of trussesto be lifted. This investigation had the participation of the site engineer and assembly subcontractors, so that their tacit knowledge could be used to build the best possible scenario for this process. Client representatives also participated in the discussions. Figure 6 illustrates this process and the screenshots images taken from the 4D model. Another visual device was produced using screenshots from that model. The virtual prototype was implemented and refined along the process, considering suggestions of improvements made by client representatives, site engineer and assembly subcontractors.

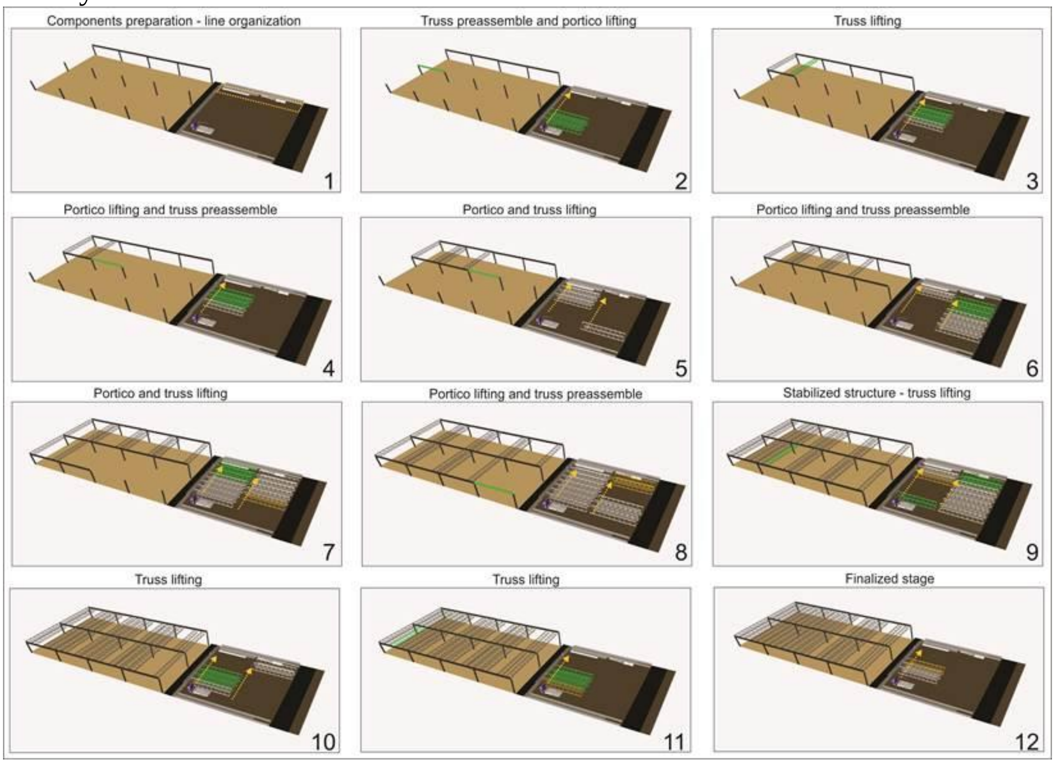

Figure 6: Screenshots of 4D simulation (critical stage detailing)

The control of this process was also part of this investigation. The productivity of this process was monitored and compared with the productivity of the initial stages of the assembly. The amount of trusses stored decreased 60% and the process productivity increased 15%. These results were relevant due to the study of the components position for pre-assembly trusses that was placed as close as possible to avoid transport operations, and to the study of lifting operations. Figure 7 illustrates a comparison between the erection plans in 4D modeling and the real construction site performed. Figure 7 (a and b) presents the assembly and pre-assembly areas near from each other to avoid transport waste. Figure 7 (c and d) show the components organization to the pre-assembly trusses near for the operation process. This comparison shows the similarities of 4D simulation model with the executed work. However, it must be pointed out that this was only possible due to the refinement of the 4D model along the process with the participation of site engineer and subcontractors.

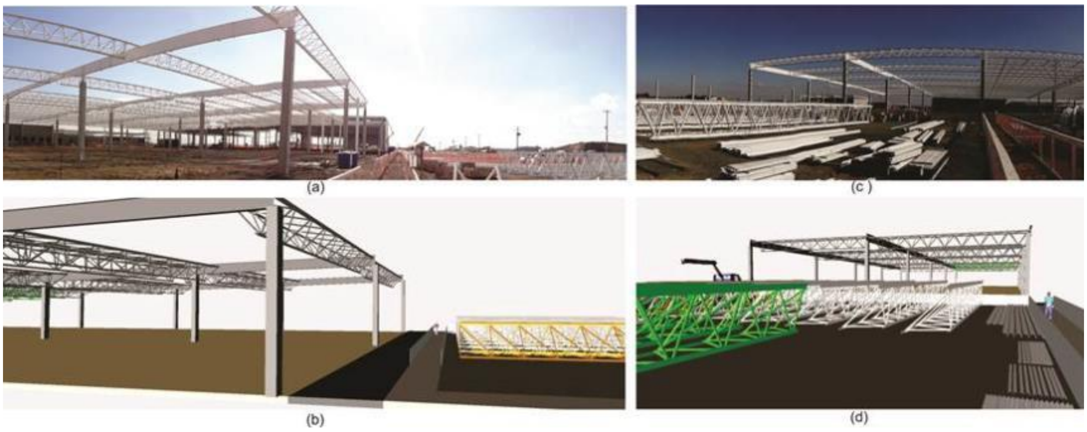

Figure 7: Comparison between as designed and as erected on site

CONCLUSIONS

In the context of engineer-to-order prefabricated building systems, it was identified the need for improvement in site logistics processes. This research brought as a result the development of logistics plan with the use of 4D BIM tools. This study highlighted the need to plan and control logistics operations in construction sites by using hierarchical approach. The initial decisions do not require a detailed BIM model, while the modelling of critical logistics operations requires a fine level of detail. Through 4D simulation, it could be analysed in detail the times of each process involved and thereby increase assembly productivity, reducing inventories and work in progress and seeking a continuous flow of production.

The combination of 4D BIM models with visual management brought an interactive process which included the participation of various stakeholders (researcher, coordinator, site engineer, assembly subcontractors and client). The board with screenshots from 4D modeling became a useful tool to implement in the construction site. The site engineer, the assembly subcontractors and the client could participate in the planning sessions in an easier way, given that they did not know how to operate the 4D modeling software. Those boards were useful for the implementation of layout and also for monitoring the work progress.

The 4D-based visual boards in combination with the LOB facilitated logistic planning by enabling the simulation of individual sequences of lifting-assembly operations duo to critical conditions. It also allowed the visualization of what-if scenario in critical process which incorporated a number of non-value adding activities. Therefore, the 4D simulation played a key-role in encouraging collaboration between the planning-assembly-erection teams in the logistic management process.

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SIMULATING AND VIZUALISING EMERGENT PRODUCTION IN CONSTRUCTION (EPIC)USING AGENTS AND BIM

Lola Ben-Alon[1], Rafael Sacks[2]

ABSTRACT

We present an agent-based simulation model developed for studying and improving production control in construction processes. The model represents individuals' decision making, knowledge and uncertainty.

Simulation methods are particularly useful for assessing the impacts of different production control methods and information flows on production on site because field experiments in building projects suffer difficulties with isolating cause and effect. Existing methods such as Discrete Event Simulation (DES) are limited to model decision-making by individuals with distinct behaviour, context and knowledge representation. Agent-Based Simulation (ABS) may offer a better solution. The simulation developed exhibits the interdependence of individual crews as they interact with each other and share resources, reflecting the influence of crew leaders' perception of the project state on their workflow decisions. The model uniquely distinguishes between reality and perceived reality. Significantly, this allows experimentation with uncertainty as agents function within the context of what they know. Different management policies, such as the LPS, can be tested, as can the impact of different site information-flow systems. Unlike the few existing agent-based simulation models for construction, the simulation is situated in a realistic virtual environment modelled using BIM, allowing future experimental setups that can incorporate human subjects and real buildings.

KEYWORDS

Agent-based modelling and simulation, building information modeling (BIM), information flow, production control, visualization.

INTRODUCTION

Until the 1990's (approximately), most researchers and practitioners held the view that there is effective "central control" behind every construction project even at the

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production level. The traditional approach supported implementing “central control” in production, in which a detailed construction plan and schedule are created in advance based on well-defined resource and temporal constraints (Morris, 1997; Hendrickson, 1998). Once a plan was created it was assumed that the project would (or should) evolve according to the plan and that interaction of construction crews and individuals would have a minimal impact on this evolution. Conversely, recent thinking suggests that production in construction may be better understood as emergent, dependent on the individual motivations and behaviours of individual crews and workers. Laufer (1997) emphasized the role of dynamism and uncertainty and therefore inherent inability of pre-planned control systems in construction, offering a set of principles for simultaneous management. Lean construction has highlighted the impact of variation in production due to misalignment of the flows of materials, crews, information, equipment and information, and the lack of management of space and external factors (Koskela, 2000).

Whereas the school of 'determinate' or 'central control' thinking pursued research to develop and refine tools based on the Critical Path Method (Antill, 1990; Lu and Li, 2003), lean construction researchers exploring production systems found simulations more appropriate. Given the availability and accessibility of Discrete Event Simulation (DES), this has been the research tool of choice (Tommelein, Riley and Howell, 1999; Esquenazi 2002; Schramm, et al., 2007; Sacks, Esquenazi and Goldin, 2007; Brodetskaia, Sacks and Shapira, 2012). DES tools such as STROBOSCOPE and CYCLONE have provided general and special purpose frameworks for simulating construction operations and construction management processes (Martinez, 1996).

However, when modelling construction work using a DES, workers are not modelled as individual entities with individual properties; rather they are treated as homogeneous resources with variation that is predetermined (usually defined by simplified, fixed probability distributions) (e.g. Brodetskaia, Sacks and Shapira, 2012). Construction crews are represented by static "machines" located along the production line, while the construction products (locations or spaces) are represented as dynamic "products" which move along the production line from one 'crew' to another. Significantly, the entities (workers, crew leaders, subcontractors, etc.) are not utility driven and lack any autonomous decision-making mechanism (Sawhney, et al., 2003; Watkins, et al., 2009). In general, the DES models have limited ability to model decision-making by crew leaders who have distinct individual behaviour that varies according their context: knowledge, perception of given conditions, commercial terms of their subcontractor employer, material supply policies, etc.

Howell (1999) points out that lean construction methods tend to shift the focus toward decentralized control, suggesting that events could be better explained based on the agent-based concept, which enables decentralization of the production. Sacks and Harel (2006) used game theoretic approaches in order to study subcontractor resource allocation behaviour, while emphasizing the need to adopt decentralized methods of control in managing projects. Thus the need arises to explore and test the possible utility of an emergent, self-organized mode of production control on a construction site. Agent-Based Simulation (ABS) (Macal and North, 2005) appears to be the most appropriate simulation tool for the task.

There have been a few attempts to use ABS to model the behaviour of individual construction entities. Some have focused on the flow of construction equipment rather than on the workers (e.g. Kim and Kim, 2010), and most use highly simplified virtual environments represented as planar grids and agents with limited decision-making mechanisms (e.g. Sawhney, et al., 2003; Watkins, et al., 2009; Lahouti and Abdelhamid, 2012).

The underlying production principle of this work is that self-organization in construction situations may give rise to decentralized, distributed, self-healing systems, which may yield productive work-flow. The envisaged emergent mode functions through interactions between individual crews as they flow through the project and communicate with the other crews, the site administration, and use a Building Information Model (BIM) that describes both the process and the product. The ABS tool described in the following sections is intended to provide researchers a multi-agent-based simulation system to evaluate different production control methods in construction, including systems designed to exploit self-organization. The system aims to mode individuals' decision making under uncertainty and the quest for information as well as the execution of work.

METHOD

The research method was to design a new experimental setup (the ABS model), devise validation tests, implement the simulation as a software tool, and validate the tool using the prescribed tests. The simulation method implements a “bottom-up” approach to model the interactions between individual agents. Agents were programmed with decision making rules and utility functions and applied to a ‘to-be-built’ environment represented using BIM. The rules and utility functions were based on knowledge of construction work processes and behaviour parameters acquired through field interviews and observations of site superintendents and trade crew leaders. By varying behavioural and situational parameters of the individual agents, such as reliability and consistency in adhering to plan, it was possible to generate aggregate system performances and outcomes similar to those observed in building projects on construction sites and to validate the system using scenarios with predictable outcomes.

SIMULATING EMERGENT PRODUCTION IN CONSTRUCTION (EPIC)

The EPIC simulation model was designed for researchers to experiment with different production control regimes. It allows them to evaluate the emergent flow of work and labour according to conditions established using behavioural and environmental parameters set by the researcher. There are two types of agents: subcontractor crews, modelled by 'crew leader' agents, and site managers ('superintendent' agent). Crew leader agents make decisions about their movement and work within the site according to their perception of the state of the project and their expected utilities. Each run of the simulation results in comparable outputs, such as the flow line of the project and time distribution charts.

Modelling the information known to each agent individually and their relative confidence in the certainty of that information is a central feature of the EPIC system because many of the candidate production systems that will be tested are decentralized and expose subcontractors to project state information in different ways. Agents acquire information as they move through work locations (represented using a BIM model), and meet other agents. The agents calculate the expected production rate as a function of their trade crew size, the congestion in the intended work locations, and the expected quantity of work, all based on their perceived or current information. They then make decisions considering both the current work plan and the potential utility. The crew leaders' utilities, and thus their decisions, are dependent on the expectations of both their employer (the subcontractor company) and the site manager (the superintendent).

The steps required to develop the simulation were:

1. Field study to observe and formulate the behaviour of the different agents.
2. Development of the detailed decision making model.
3. Implementation of the experimental simulation tool according to the observations and the constructed model.
4. Validating the tool by through test simulations of predictable scenarios.
5. Experimentation with simulations of unpredictable scenarios.

FIELD STUDY

The knowledge needed to define the agents' behavioural algorithms was collected through in-depth interviews of 13 construction employees (subcontractors, crew leaders and superintendents) engaged in finishing works in four high-rise tower projects. Data for production rates, material consumption quantities and other parameters was collected at the same time. The most interesting observations from the interviews were the following:

Economic Utility Function. Crew leaders take into account their employer's perceived profitability, attributing importance to the subcontractor's economic utility.

Maturity Factors. The perceived maturity of a certain work package, according to the crew leaders, was observed to increase whenever there were sufficient clear design information, available sufficient materials and equipment, and the space is ready in terms of pre-work. They intuitively understood and acted on their perceptions of the maturity of the work packages.

Reliability of Information. The actual maturity of the pending works and their scope often differ from the superintendents' and/or the crew leaders' perceptions of the maturity and scope.

Working Prior to Receiving Design Information. Crews are often sent by the superintendent to perform work where design information is still missing, with the intent to prevent further delays in subsequent trades. This often causes re-entrant flow and re-work.

Leaving Small Parts of Work Packages for Later Completion. Crew leaders tend to prefer to maintain productivity, leaving small parts of work packages that have lower than average productivity for later completion.

Conflicting Instructions. Crew leaders are employed by the subcontractor, their direct employer, whereas in their day to day routine they are subject to the superintendent, the manager nominally in charge of production on the construction site. Under these circumstances (having two sources of authority), crew leaders often find themselves conflicted as to which tasks should be performed at any given time. In day to day practice, crew leaders deliberate whether to prefer the subcontractor's utility or the superintendent's instructions.

Primary Decision Outcomes. When faced with the option of what to do next, crews chose between four main paths: to select a new task and begin work, to continue working on their current task, to wait for work to become available, to gather information (where certainty was low concerning the project state), or to abandon the construction site.

DECISION MAKING MODEL

The agents' behaviour was modelled using Behaviour Trees (BT), an Artificial Intelligence (AI) technique for modelling decision making used in commercial games. Behaviour trees allow simple and scalable solutions for editing logic. Processing begins from a root node and child nodes are evaluated from left to right in order of priority. From the interviews with the crew leaders, the following routine was observed and modelled as a crew leader agent BT:

Sensory System (sight of other objects and agents).The agents exchange information while meeting (coming in contact with) the superintendent agent. Moreover, the crew leader agents copy actual information observed in their surroundings.

Perform Work in the Chosen Location. Working activity will occur if all the sufficient conditions are held: Presence of materials, availability and that there is still some amount of work to be completed.

Select Where to Work. If working activity fails, then the agent will evaluate its future utility from all available work packages. This node incorporates a utility function derived from the work of Sacks and Harel (2006) but modified to account for perceptions the maturity of different pre-conditions.

Gather Information Regarding the Maturity of the Different Work Packages. If the work selection activity fails, and certainty towards available work packages is low, then the crew leader agent will try to gather information. The information gathering activity may be done be several communication methods: by going physically to the working location to collect the information, or by requesting information from the superintendent.

Wait at the Construction Site. When gathering information fails (for instance if the certainty of low utility is high, but the time until a high utility work package will become available is shorter than the appropriate parameter), then the agent will wait.

Abandon the Construction Site. Finally, the agent will choose to abandon the construction site if waiting activity fails. Failure of waiting activity may occur if the time until a mature work package is long. In future models, abandonment may also occur if a work package with sufficiently higher utility is available on an alternative project.

IMPLEMENTATION OF THE EPIC SIMULATOR

The full-scale ABS model was implemented in the UNITY 3D game engine. One of the novel features of the simulation is the ability to reflect the influence of project state perception on crew leaders' workflow decisions. The BIM model objects each have a property that reflects their state of completion through the performance of work on them for each trade. A separate Excel table, also with cells for the state of completion of each BIM element for each trade, is maintained for each crew leader agent. At any given time during a simulation run, a crew leader's table reflects the 'knowledge' of that crew leader about the project state, which may or may not be the same as the actual state. Crew leader's decisions are made on the basis of their own knowledge table. Their tables are updated by mechanisms that can be controlled by the researcher: through interaction with the supervisor, through meetings such as LPS, or by 'seeing' the physical state when present in a location. An artificial 'full information' state can be modelled by copying the BIM object property values to the crew leaders' knowledge tables whenever they are changed.

Thus different management policies, such as the LPS, can be tested, as can the impact of different site information-flow systems. The model reflects the reliability of information, and distinguishes between reality and perceived reality. Significantly, this allows experimentation with uncertainty as agents function within the context of what they know.

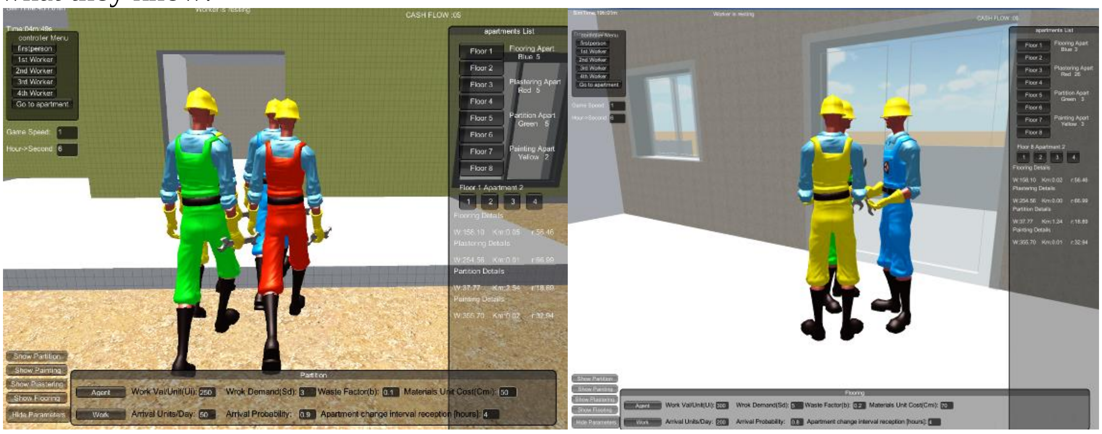

Figure 1: Different views from the simulator prototype.

VALIDATION AND TESTING

The EPIC simulation was validated by running it for seven scenarios whose results could be predicted without simulation, and comparison of the results. Examples are scenarios in which all crew leaders conform to the initial construction plan and all materials and information are delivered on time, or all crew leaders ignore the plan and prefer their own productivity. The test results confirmed that the input parameters, when varied independently of other parameters, had the predicted effect.

The system was also tested with three additional experimental scenarios in which a variety of input parameters were mixed, such as with or without LPS weekly work planning meetings, different information transfer patterns, different degrees of variation in the rate of supply of design information, and different degrees of discipline in adhering to plan. These experiments demonstrated the emergence of different patterns of flow of construction trade crews, generated due to agents' characterization, materials and design information supply, as well as work conditions. In general, agents that organize their work flow according to economic utility generated lower amounts of re-work and re-entrant flow, while having greater amounts of transition time between work packages, due to the preference of work packages with high maturity, even if not adjacent to current location. Accordingly, the model allows modification of the transition fee within the economic utility function, giving rise to proximity preference.

Figure 2 shows the flow line and the arrival intervals of new design information for a scenario in which different crew leaders' agents have different motivations. Agents representing crew leaders of trade crews A,B and C are work plan driven: they will prefer to work according to the initial plan, which in this case is chronologically ordered from the first to the last floors. It can be seen that due to their rigidity to the work plan, they work in work packages though no design information has arrived, returning to some amount of rework. In contrast, agent D is economic utility driven. Accordingly, agent D does not attempt to execute tasks which were completed by previous trades while missing complete design information. It is only when the trades complete their re-work that the crew leader attempts to perform the work package.

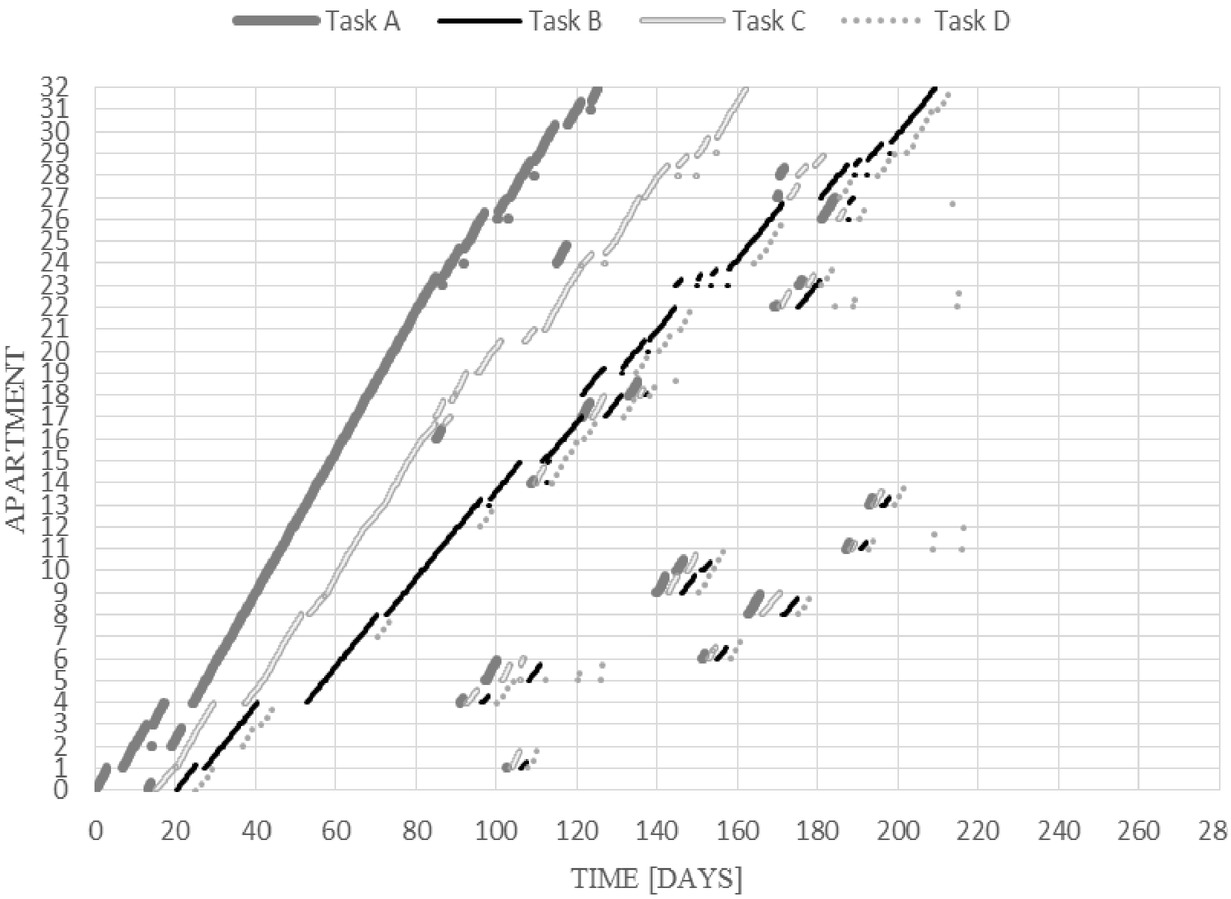

Figure 2: Flow line of the ninth scenario, together with the arrival of new design information (in plans)

As expected, the time distribution of crew leader D, as shown in Figure 3, exhibits no tasks performed without design information, as well as no re-work. However, the agent has a long period of waiting, due to the need to wait for completion of prior trades.

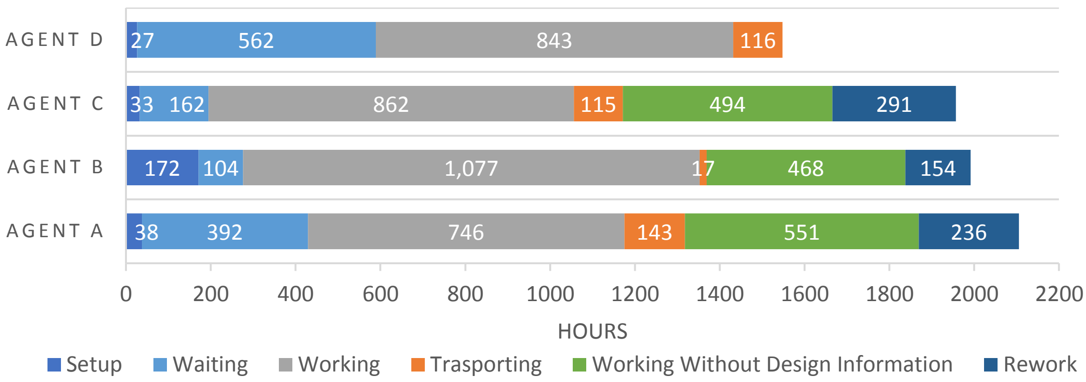

Figure 3: The time distribution of each of the crew leaders' agents in scenario 9.

CONCLUSION

The results exhibit the interrelation between the researchers' input parameters, the trade crew agents' decision-making, and the emergent patterns of production sequence and productivity. By varying parameters of material supply stability, arrival of design information, and agent' behaviour (which varies from agent to agent according to contextual parameters like contract type, work demand, motivation etc.), we were able to generate different aggregate system performances. The resulting patterns for known conditions proved similar to those found in an actual project context on a construction site. Significantly, simulation runs with arbitrary parameter values resulted in production patterns that could not be predicted, demonstrating the emergent nature typical of real project outcomes.

The contribution of this research lies in the development and testing of the ABS and demonstration of its utility for testing the potential of different modes of production control and commercial terms on a construction site. Lean construction and BIM research has revealed the potential of novel ways to organize production on site that exploit the benefits of pull flow and thorough yet flexible planning. The EPIC simulation platform is uniquely capable of testing their impact because it models the complex, emergent patterns of production behaviour that result from the interaction of the myriad subcontracting teams and suppliers that perform construction work on and off site. In particular, the influence of each participant's knowledge, context and motivations on their day to day decisions about resource allocation and work sequence can be modelled in the ABS, while they could not be modelled using DES. Thus EPIC provides the first thorough, yet straightforward and reliable, tool to test different ideas for production control paradigms in construction that takes individual behaviour and uncertainty into account.

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CONSTRUCTION AND DEMOLITION WASTE MANAGEMENT USING BIM TECHNOLOGY

Jack C.P. Cheng[1], Jongsung Won[2], and Moumita Das[3]

ABSTRACT

The amount of waste generated in construction and demolition (C&D) processes is enormous. Construction wastes are mainly generated due to improper design, poor procurement and planning, inefficient material handling, residues of raw materials, and unexpected changes in building design. Building information modelling (BIM) can efficiently manage the C&D waste by avoiding design problems, changes, and rework. This paper investigates the potential of BIM technology for supporting building design and construction processes to manage C&D waste. In particular, BIM-based approaches that can reduce, reuse, recycle, and manage construction waste through clash detection, quantity take-off, planning of construction activities, site utilization planning, and prefabrication are proposed in this paper.

KEYWORDS

Building information modeling (BIM), collaboration, process, waste management, work flow.

INTRODUCTION

The amount of waste generated in construction and demolition (C&D) processes is enormous. For example, C&D waste comprises of 25~40% of the solid waste in the United States (Winkler, 2010) and contributes around 25% of the solid waste disposed at landfills in Hong Kong (Hong Kong Environment Protection Department, 2013). C&D waste is mainly composed of wood, asphalt, drywall, concrete, and masonry (Yeheyis, et al., 2013). Construction wastes are mainly generated due to improper design (Gavilan and Bemold, 1994), poor procurement and planning (Formoso, et al., 2002), inefficient material handling (Poon, Yu and Jaillon, 2004), residues of raw materials (Formoso, et al., 2002), and unexpected changes in building design (Jaillon, Poon and Chiang, 2009). The causes of C&D waste can be resolved through integrated building design and better construction planning and management,

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which could be facilitated by building information modelling (BIM) and lean construction. BIM provides the basis for improved planning and scheduling and helps to ensure just-in-time arrival of people, equipment, and materials (Eastman, et al., 2011). A visual interface to a BIM model would enable managers to visually select the work packages for immediate execution and have their material requirements measured automatically and compiled for delivery (Sacks, Treckmann and Rozenfeld, 2009b). Lean construction also eliminates waste from the processes to improve construction planning and management and then reduced material waste by 64% (Nahmens and Ikuma, 2012). Furthermore, integration between BIM and lean construction can create the synergy effects on construction sites by improving the processes (Sacks, et al., 2009a; Sacks, Treckmann and Rozenfeld, 2009b). Integrated building design can avoid design problems and changes, thereby reducing C&D waste generation. Better construction planning and management can also significantly reduce the generation of C&D waste by avoiding construction rework, unnecessary handling and unused raw materials. Porwal and Hewage (2012) claimed that BIM implementation reduced rebar waste by 1.6%. Liu, et al. (2011), Rajendran and Gomez (2012), and Ahankoob, et al. (2014) introduced the potential use of BIM technology to minimize construction waste, but these efforts were limited to the design phase and did not discuss the specific methods to utilize BIM for C&D waste minimization.

This paper investigates the potential use of BIM technology for supporting building design as well as construction processes to manage C&D waste. BIM-based approaches to construction waste management and minimization through design validation, quantity take-off, phase planning, site utilization planning, and digital prefabrication are reviewed and discussed in this paper. These BIM-based approaches are parts of the processes and work flows that involve different participants in an architecture, engineering, and construction (AEC) project for C&D waste management planning and execution. The structure of this paper is organized as follows. The next section introduces previous studies on C&D waste management using traditional ways and BIM. BIM-based approaches to C&D waste management and minimization are then proposed, followed by the conclusions.

LITERATURE REVIEW

Many previous research has been conducted to minimize the amount of C&D waste (Lawton, et al., 2002; Jaillon, Poon and Chiang, 2009; Meibodi, Kew and Haroglu, 2014). Meibodi, Kew and Haroglu (2014) explored various methods to minimize concrete waste on site and identified key factors for waste minimization by conducting a questionnaire survey. Prefabrication and procurement management were identified as the most recommended methods for minimizing concrete waste (Meibodi, Kew and Haroglu, 2014). Jaillon, Poon and Chiang (2009) analyzed an impact of prefabrication on waste reduction in Hong Kong and the average wastage reduction rate was 52%. Lawton, et al. (2002) estimated reduction of 70% in concrete waste by using prefabrication. However, there were insufficient techniques and tools for reducing construction waste during the design and procurement stages (Liu, et al., 2011).To minimize and manage C&D waste, we need an integrated management approach and process improvement because C&D wastes are generated due to improper design, procurement and planning, inefficient material handling, residues of raw materials, and unexpected changes (Poon, Yu and Jaillon, 2004; Yeheyis, et al., 2013).

Lean strategies have been proven effective in improving processes and performance (Song and Liang, 2011) by eliminating wastes from the process (Nahmens and Ikuma, 2012). Particularly, material waste reduction was achieved through lean construction (Huovila and Koskela, 1998; Nahmens, 2007; Nahmens and Ikuma, 2012). Lean construction resulted in a significant environmental effect by reducing material waste by 64% (Nahmens and Ikuma, 2012). BIM can also enable us to minimize the amount of C&D solid waste by improving quality and accuracy of design and construction, thereby reducing design errors, rework, and unexpected changes. Therefore, several previous studies have proposed BIM-based systems or methods to manage C&D waste (Cheng and Ma, 2013; Hamidi, et al., 2014; Park, et al., 2014) and have introduced potential use of BIM to minimize C&D waste (Liu, et al., 2011; Porwal and Hewage, 2012; Rajendran and Gomez, 2012; Ahankoob, et al., 2014). Park, et al. (2014) developed a demolition waste database system based on BIM, whereas Hamidi, et al. (2014) proposed a BIM-based demolition waste management system. Cheng and Ma (2013) leveraged the BIM technology to develop a system for C&D waste estimation, disposal charging fee calculation, and pick-up truck planning. However, these studies did not proposed specific methods to minimize and manage C&D waste. To minimize C&D waste, we should manage and eliminate causes of C&D waste. Porwal and Hewage (2012) proposed a BIM-based model to analyze reinforced concrete structures to reduce waste rate of reinforcement. The model simulated architectural and structural design requirements and compared results to make necessary changes in the designs to reduce and reuse rebar waste. Although Porwal and Hewage (2012) reduced the amount of rebar waste by selecting proper length of rebars and considering available cut-off lengths, the paper focused on minimizing waste rate of structural reinforcement and did not provide a method to reduce the amount of C&D waste such as concrete and glass in general. These materials are also typical C&D wastes. Rajendran and Gomez (2012) claimed that waste could be minimized through designing-out-waste by using BIM tools. Liu, et al. (2011) and Ahankoob, et al. (2014) explored the potential application of BIM to minimize waste on a construction site by conducting in-depth literature review and analyzing causes of construction waste and current practices of waste minimization. However, they did not concretely provide how to use BIM for C&D waste minimization and management. Therefore, this paper aims to introduce and discuss the BIM-based approaches to C&D waste and disposal management. The BIM-based approaches can be integrated with lean construction to minimize and manage C&D waste by improving construction processes.

BIM-BASED C&D WASTE MANAGEMENT

C&D WASTE MANAGEMENT

C&D waste management planning consists of minimization and disposal plans. C&D waste minimization is categorized into 3R that includes reducing, reusing, and recycling the waste. Reduction is the first step to minimize C&D waste generation and the generated C&D waste should be reused and recycled to minimize disposal waste. C&D wastes that are not reused or recycled should be disposed at disposal facilities and managed. Efficient management of disposal waste is also based on calculating disposal waste amount, charging fee, and required number of hauling trucks in advance. Therefore, precise estimation and planning of the amount of 3R and disposal of waste are fundamentals of waste management planning and execution. Based on these activities, C&D waste can be minimized and monitored efficiently.

BUILDING INFORMATION MODELING (BIM)

BIM is not only a technology innovation, but also a significant shift in the overall AEC processes. Improvement of productivity and reduction of project duration and cost by using BIM have been demonstrated in many projects (Eastman, et al., 2011). Furthermore, BIM can reduce waste-related costs and materials in construction projects (Krygiel and Nies, 2008). However, there has been no technique and tool available that explores BIM as a platform to minimize C&D solid waste. Therefore, this paper investigates how BIM can be implemented to minimize and manage C&D waste on a construction site. Typical BIM uses that can be implemented in planning, design, and construction phases were identified through literature review (Table 1). The BIM Project Execution Planning Guide (Anumba, et al., 2010), which has been referenced by many BIM guidelines and standards because this was an early version of the BIM guideline, introduced various BIM uses and their descriptions. The BIM Guideline of New York City (Bloomberg, Burney and Resnick, 2012) also presented BIM uses, but the BIM uses were similar to those of the BIM Project Execution Planning Guide.

Table 1. BIM Uses in Plan, Design, and Construction Phases

BIM use	Phase		
	Plan	Design	Construction
Existing conditions modeling	O	O	O
Quantity take-off (cost estimation)	O	O	O
Phase planning (4D simulation)	O	O	O
Programming	O	O	
Site analysis	O	O	
Design reviews	O	O	
Design authoring		O	
Engineering analysis		O	
Code validation		O	
3D coordination (clash detection)		O	O
Site utilization planning			O
Construction system design			O
Digital fabrication			O
3D control and planning			O

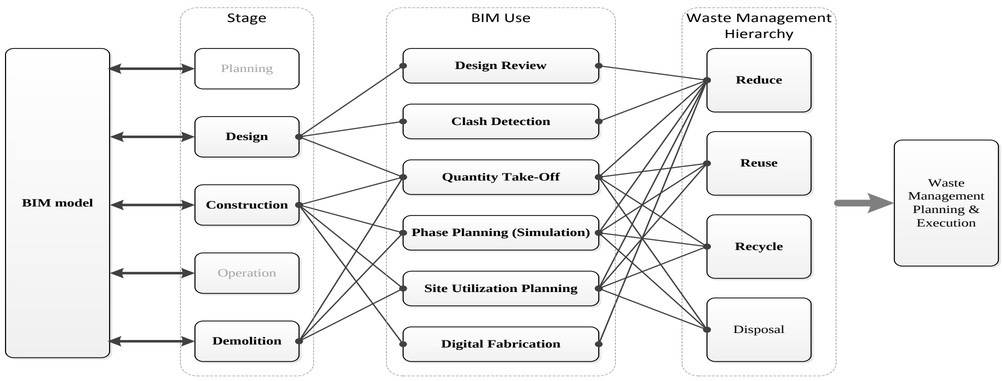

Figure 1. BIM-based Approaches to C&D Waste Management

We investigated potential application of several BIM uses that can reduce improper design, residues of raw materials, and unexpected changes in building design and improve procurement, site planning, and material handling in construction management. The BIM uses selected in this paper were quantity take-off, phase planning (or 4D simulation), design reviews, clash detection (or 3D coordination), site utilization planning, and digital fabrication. Figure 1 shows the BIM-based approaches to manage C&D waste in design, construction, and demolition phases. The proposed approaches are not simply technologies, but also involve a process shift that involves different project participants. Therefore, collaboration among participants is required for BIM-based C&D waste management, which is aligned with lean construction. The selected BIM uses can also reduce various types of waste that can be removed by lean construction. Although the typical types of waste related to lean construction are waiting, motion, processing, over-production, conveyance, inventory, and correction waste, this paper focused on the types of waste that can affect C&D waste management, which were over-production, conveyance, inventory, and correction wastes. Table 2 shows the types of waste that can be reduced with each BIM use through literature review (Young, et al., 2009; Eastman, et al., 2011; Azhar, 2011). These wastes are managed by lean techniques like Just-In-Time, total quality control, continuous improvement, and value-based strategy (Eastman, et al., 2011; Azhar 2011). The approaches to implement the selected BIM uses and lean construction in order to minimize and manage C&D waste will be further discussed in this paper.

Table 2.Relations between BIM uses and types of waste

BIM use	Waste type			
	Over-production	Conveyance	Inventory	Correction
Design validation		O	O	O
Quantity take-off	O	O	O	O
Phase planning		O	O	O
Site utilization planning		O	O	O
Digital fabrication	O	O	O	O

DESIGN VALIDATION – DESIGN REVIEWS AND CLASH DETECTION

Design errors are common in the AEC industry because a building consists of components which are designed by different project participants such as architects, structural engineers, and mechanical, electrical, and plumbing (MEP) engineers. These design errors may lead to rework and C&D waste. BIM-based approaches to C&D waste minimization by eliminating design errors detected in construction are design reviews and clash detection. Design review is implemented to quickly analyze design alternatives and resolve design and constructability issues. Clash detection is a coordination process to determine field conflicts by comparing 3D models of building systems and eliminate the conflicts prior to installation (Anumba, et al., 2010). Detecting and resolving building element clashes and other causes of rework were chosen as the most beneficial ways of using BIM (Young, et al., 2009) and have become common BIM practices, called a BIM-based design validation process. BIM-based design validation can improve design quality by reducing the number of design errors, change orders, and rework (Khanzode, Fischer and Reed, 2008; Williams, 2011). Khanzode, Fischer and Reed (2008) found that the rework costs in electrical work in a hospital project were reduced to 0.2% of the work costs through BIM implementation, although 1–2% of electrical work costs is generally incurred as rework costs due to design changes in similar projects. Consequently, the design validation can reduce the amount of C&D waste by preventing change orders and design errors in design and construction phases. Lean construction also reduces correction waste producing a part that is scrapped or requires rework. Integration between BIM and lean construction can create a synergy effect on C&D waste reduction by eliminating rework.

QUANTITY TAKE-OFF

C&D wastes are generated due to improper residues of raw materials and poor procurement and planning (Poon, Yu and Jaillon, 2004; Yeheyis, et al., 2013). Therefore, it is important to accurately estimate the amount of materials required on a construction site to reduce unnecessary raw materials and improve a procurement process. A process in which a BIM model can be used to accurately perform quantity take-off in the design and construction processes and provide modifications with potential to save time. The BIM-based quantity take-off as well as lean construction prevents the amount of over-production producing unnecessary materials. Furthermore, BIM-based quantity take-off can explore different design options and concepts by considering the perspective of C&D waste management. Based on quantity take-off, proper length, area, or volume of materials can be ordered. Furthermore, available cut-off length, areas, or volume can be considered to maximize the amount of C&D waste that can be reused and recycled. Porwal and Hewage (2012) claimed that consideration of proper length of rebar and available cur-off length reduced 1.6% of waste of structural reinforcement by maximizing the reuse rate of remained rebar. Remained materials should be appropriately stored to reuse them for other activities on a construction site or dispose. While the remained materials are stored for other purposes, additional C&D waste may be generated due to inefficient material handling. Therefore, we need a plan to manage the remained raw materials on site.

BIM-based quantity take-off can also be utilized in demolition and renovation projects. Accurate quantity take-off using BIM can help calculate the amount of C&D waste, disposal charging fee, and required number of pick-up trucks (Cheng and Ma, 2013). The precise results help participants manage waste. Cheng and Ma (2013) compared the total volume of demolition waste estimated by using the Spanish model provided by Solis-Guzman, et al. (2009) and BIM. The total volume of demolition waste based on the traditional way was 15.8% different from the result using BIM.

PHASE PLANNING (4D SIMULATION)

Phase planning based on integration of a schedule and BIM model enables to effectively plan the phased occupancy and show the construction sequences and space requirements on a construction site. BIM model can be integrated with planning of human, equipment, and material resources for better schedule and quantity, identify, and resolve space and work space conflicts ahead of the construction process (Anumba, et al., 2010). A well-planned and smoothly-executed construction process can reduce errors, rework, and generation of C&D waste.

Procurement status of project materials can be monitored through BIM-based phase planning. The right amount of right materials should be delivered and made available on site when they are required because early material delivery may lead to inventory problems, unnecessary moving, and material deterioration due to weather conditions, which could increase the amount of C&D waste. BIM can also track and manage the supply chains of different building components and materials. Precise scheduling enables just-in-time delivery of materials and equipment, reduction of the amount of C&D waste by decreasing a likelihood of damages, and maximization of reusing and recycling rate of generated C&D waste by forecasting appropriate time to use the remained waste. The generated disposal waste can be also managed efficiently by forecasting accurate location and time that disposal waste will be generated on site.

SITE UTILIZATION PLANNING

Inappropriate material handling is one of the major causes to generate unexpected C&D waste. Better site layout planning improves the movement of materials and reduces the number of double handling of materials, which effectively reduce material wastage by reducing the number and distance of material handling (Ahankoob, et al., 2014). Site utilization planning based on a 4D model and quantity take-off graphically can calculate the amount, location, and time of expected C&D waste to be reused, recycled, and disposed on site with the construction activity schedule. Equipment and storage space for reusing, recycling, and managing C&D waste can be analyzed and planned.

DIGITAL PREFABRICATION

The use of precast concrete and prefabricated steel elements can reduce C&D waste on site. The use of prefabricated elements could reduce the amount of construction waste by 52% (Jaillon, Poon and Chiang,2009). However, prefabrication is technically challenging because accurate dimensions are required early in the design process and proper installation is then needed on site. BIM digitally provides accurate detailed geometrical representation of each building component and allows the geometrical information to be exported to data formats used in fabrication shops. Fabricators can manage and automate a fabrication process using information extracted from BIM models. Moreover, BIM-based digital prefabrication enables lean construction and material handling efficiently by reducing the number of material handling on site.

WORK FLOW OF BIM-BASED C&D WASTE MANAGEMENT

Since the selected BIM uses for C&D waste management change design and construction processes, they may also affect work flows for waste management (Figure 2).To reduce C&D waste in design and construction phases, design errors, change orders, and reworks should be eliminated through BIM-based design validation, quantity take-off, and digital fabrication.

The first step for BIM-supported C&D waste estimation is to extract quantities of each material from a BIM model and integrate them with a construction schedule. Based on quantity take-off and a predefined C&D catalogue, we classify C&D waste into inert waste like concrete and non-inert waste like wood without additional time and efforts. Then, the volume of C&D waste, disposal charging fee, and required number of pick-up trucks can be accurately estimated using the waste index and help architects and contractors plan C&D waste management at the beginning stage of a project. The C&D waste generated on the construction site can be managed efficiently through site utilization planning based on BIM models that are integrated with the quantities and project schedule.

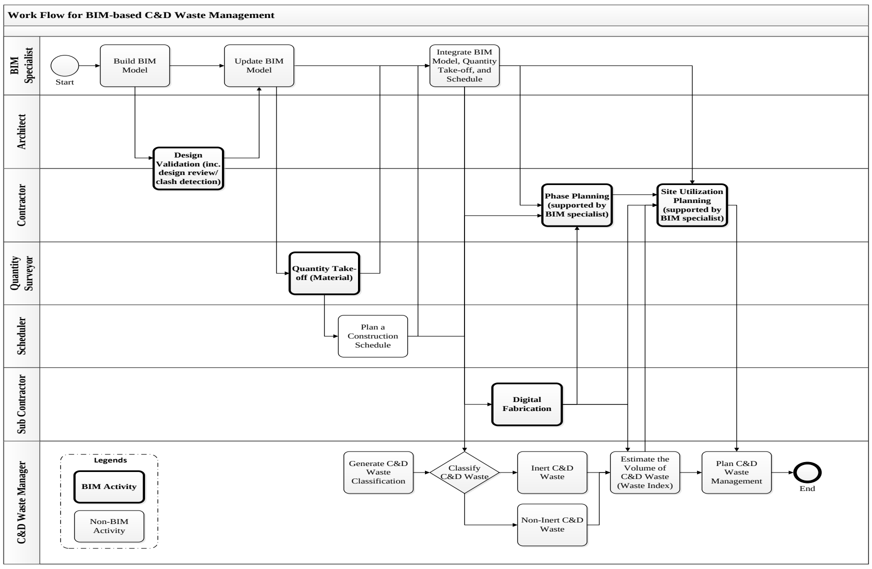

Figure 2. An Example of the Work Flow for BIM-based C&D Waste Management

CONCLUSIONS

C&D wastes are generated due to improper design, poor procurement and planning, inefficient material handling, residues of raw materials, and unexpected changes in design, construction, and demolition phases. This paper investigates the potential of BIM technology for supporting integrated building design and construction processes to eliminate the major causes of C&D waste generation and manage the waste. We explored that C&D waste could be reduced through design reviews, clash detection, quantity take-off, phase planning, site utilization, and digital prefabrication. In addition, C&D waste could be reused and recycled by managing a process based on quantity take-off, phase planning, and site utilization planning. The minimized and disposed wastes could be monitored by BIM-based waste management planning and execution. Integration between BIM and lean construction can create the synergy effects on C&D waste reduction on site by eliminating waste from processes.

Since the BIM-based approaches and lean construction focus on the process changes that involve different types of project participants, close collaboration among them is required for C&D waste management. However, this paper does not provide expected or actual benefits associated with C&D waste minimization and management using the proposed BIM-based approaches. In the future, these approaches will be attempted in pilot BIM projects to evaluate the actual effectiveness of BIM for minimizing and managing C&D waste in AEC projects.

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HOW TABLETS CAN IMPROVE COMMUNICATION IN CONSTRUCTION PROJECTS

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ABSTRACT

Lack of adequate communication tools can cause information losses in construction projects. The most efficient way for construction personnel to manage information on sites is to retrieve information at the point where they are and at the time when they need it. This has been difficult to achieve as information management normally involves paper-based documents. However, the rapid development of mobile information and communication technologies are offering new possibilities for portability and access to information at the construction sites.

This paper aims at exploring the effect tablets have on communication in construction projects, through a literature study, a document study, and an exploratory study with interviews of different key stakeholders in the architecture, engineering and construction (AEC) industry. The result of this study shows that tablets can enrich the communication between design and construction practitioners, and help reduce waste such as unnecessary transportation and rework caused by errors due to old, wrong and irrelevant drawings. However, tablets also entail initial costs of training and equipment, and is highly dependent on internet accessibility. This study can help AEC practitioners and academics to understand the strengths/challenges of using tablets as a communication tool at the construction site.

KEYWORDS

Lean construction, waste, flow, tablets, communication

INTRODUCTION

The construction industry is entirely reliant upon efficient communication between individuals, teams and organizations (Dainty, Moore and Murray, 2006). Due to its specific characteristics, the industry forms a complex communication environment. Furthermore, with the current imperative to improve industry performance by

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designing and constructing faster, many processes that are reliant upon efficient communication occur concurrently. Dainty, Moore and Murray (2006) state that this increases the probability of problems occurring in the transmission and reception of vital information to the construction effort.

According to Blokpoel (2003), lack of adequate communication tools is considered to be one of the most important factors for information losses in traditional construction projects. Information losses often result in errors due to old, wrong or irrelevant documents (Blokpoel, 2003). Further, this leads to iterations. Iterations in the construction phase is usually called rework and is clearly a type of waste to be avoided. According to Ballard (2000) completing assigned tasks is a central principle of lean construction, both for the reduction in waste involved in making multiple visits to the same work location and for increasing plan reliability. This has further positive impact on efficiency.

An efficient production management system also relies on accurate and timely information availability. According to Koskela (1999) one of the 7 preconditions in the Last Planner process of production planning is that sufficient and correct plans, drafts, and specifications have to be present. The research of Lindhard and Wandal (2012) shows that one of the reasons for non-ready work assignments are outdated drawings. Lack of access to accurate construction information in the site meetings, or when controlling activities out in the field, will increase the share of non-value adding activities.

The most efficient way for construction personnel to manage information on sites is to retrieve or capture information at the point where they are and at the time when they need it (Chen and Kamara, 2008). This has been difficult to achieve with traditional information management methods, which normally involves paper-based documents. Bowden, et al. (2004) indicates that the main type of information that onsite construction personnel receive and transmit is paper-based. This poses a major constraint for communication on site. However, the rapid development of mobile and wireless communication technologies offers new possibilities for portable information systems and communication tools to construction personnel (Lofgren and Rebolj, 2007). The use of mobile devices, like tablets, has entered the construction sites in large parts of the world. However, implementation of tablets requires resources and reorganizing.

This paper aims at exploring the effect tablets have on communication in construction projects, and to present strengths and challenges with the use of tablets as a communication tool at the construction site.The main questions addressed in this paper are:

- How can tablets contribute to communication between design and construction practitioners?
- What are the strengths and challenges of using tablets to communicate between design and construction practitioners?
- What initiatives can lead to tablets providing better communication between design and construction practitioners?

RESEARCH METHODOLOGY

The research includes a literature review, a study of internal documents and in depth interviews with different stakeholders in the AEC industry. These methods were conducted in order to obtain an overview of previously written literature on the topics and then study the issue deeper using internal documents and interviews. The literature review focused on information flow at the construction site, and how the use of mobile computing can enhance the information management between stakeholders during the construction phase. The approach was to search for keywords in research databases and library databases. Literatures are also found in reference lists of articles. The study primarily aimed towards academic journals, conference papers and books found at the university library.The study of internal documents aimed at documents from Veidekke Entreprenør AS, a contractor company in Norway. These documents concern the currently available applications for tablets available in today's market.

Nine semi-structured interviews with both design and construction personnel were conducted. The respondents were mainly project managers and foremen from contractors and design consultants working close to the construction site. A representative from an application developer was interviewed in order to reveal new aspects of interest. There are limited projects that utilize tablet potential to the fullest. Therefore, it was necessary to go to three different construction companies to gain experience in several areas.

THEORETICAL FRAMEWORK

INFORMATION FLOW AT THE CONSTRUCTION SITE

A study carried out by Tenah (1986) shows that a manager or supervisor cannot perform his or her functions efficiently without accurate, timely and relevant information on which to base decisions. The flow of information significantly affects all other resource flows, and is therefore important to manage from a lean perspective (Dave, Boddy and Koskela, 2010; Sacks, Radosavljevic and Barak, 2010).

Waste in construction includes delays, quality costs, rework, unnecessary transportation trips, long distances, improper choice of management, methods or equipment, and poor constructability (Koskela, 1992; Alarcon, 1997). Studies show that waste often occur due to poor information management. The research of Love and Li (2000) demonstrates that during construction, rework arises out of incomplete and incorrect information. Their work indicates that rework results in inactivity and inefficient work in several activities at the construction site.

To solve a site problem, production management personnel have to run back and forth between the construction site and their computers inside the site office. According to Lofgren (2007), documentation of building activities, production meetings and various inspections often have to be carried out twice; once when they are actually occurring and then again in a computer document. This leads to inefficient use of managerial resources due to unnecessary transportation, and a production management team that is occupied with their computers a large part of their working hours. Samuelson (2003) claims that the fact that the information needs and communication behaviours at the construction sites are not adequately met, explains the low productivity figures in the construction industry.

According to Lofgren (2007), the quantity of information that is passed to the construction site can be overwhelming, and it often generates poor quality of information in the field. As a result, construction personnel are forced to deal with slow problem solution and construction rework.

Tenah (1986) stated that the information needs of each project team member are linked to their management responsibilities. He divided the construction personnel into five levels, each with different management responsibilities and information needs. The functional management level at the site includes field engineers, the general superintendent, the superintendent and the foreman. The major responsibilities of the managers and supervisors at this level are to organize, supervise and coordinate personnel, equipment, materials and services. The information needs of the foreman consist of drawings, specifications, contract documents, local union activities, safety regulations labour agreements, quality control, progress and field performance reports.

MOBILE COMPUTING AND CONSTRUCTION INFORMATION MANAGEMENT

The rapid development of wireless networks and mobile computing have now enabled new possibilities of portability and on-demand access of information systems and communication tools that the production organization is requesting.

According to Rebolj and Menzel (2004) the concept of mobile computing consists of three components: computers, networks and mobile applications. Computers include laptops, tablets, mobile phones, and wearable computers. Networks include all types of wireless network and satellite networks. Mobile applications are the key factor that responds to specific characteristics of mobile computing and wireless networks and support users' work process by enhancing the efficiency in information communication. Based on Chen and Kamara (2008), there are three types of mobile applications that are used in the construction industry.

- Mobile CAD applications for interacting with drawings at the construction site
- Data capture applications for managing on-site information
- Project management applications for monitoring and controlling the construction process at the construction site.

Lofgren (2006) studied two tablet computer pilot projects initiated in 2005. The projects focused on the management of drawings and specifications used on the construction site from user's perspective. There are, to the author's knowledge, few published studies on use of tablets at construction sites from user's perspective since 2006. The use of tablets and the range of application areas have increased sharply the last 10 years. It is therefore of importance to continue to study the field, to ensure that the development is going in the right direction.

COMMUNICATION WITH TABLETS

Figure 1 illustrates the richness and effectiveness of communication channel. The figure shows that a rich communication channel is the most effective one. Non-verbal communication, artifacts and latency are important factors affecting the richness of the communication channels. Whiteboards provides the ability to draw and illustrate while talking, and a face-to-face conversation with a whiteboard is therefore high on the scale. A tablet can provide the same ability, while also adding an extra dimension in the form of 3D models. A tablet can therefore provide a rich and effective communication, and it is possible to take it in the field.Conversations through tablet can also take place using email, live chat and video chat without the need to be collocated.

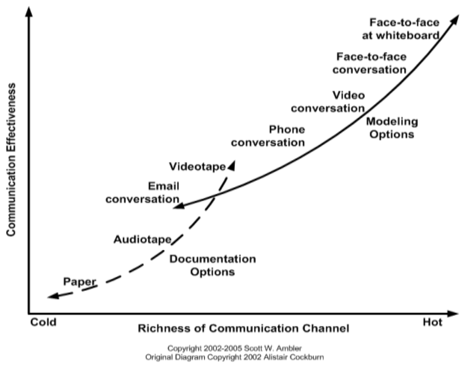

Figure 1: Richness of communication channels(Ambler, 2002)

FINDINGS AND DISCUSSIONS

Tablets are used by people with typical control responsibilities, like project managers, construction managers, superintendents and foremen. Design consultants and client representatives also use them. The majority of the respondents primarily use tablets as a tool to obtain information in design meetings, cite meetings and out in the field. However, there is a number of other applications related to the use of tablets. Based on interviews and internal documents, it is discovered nine different areas of application:

- Access to blueprints in portable document format (PDF)/drawings (DWG) file format and building information models (BIM) everywhere
- Delegating and monitoring of tasks and responsibilities
- Measurement and monitoring of the progress
- Documentation work on site
- Quality assurance work and safety inspections
- Obtaining direct measurements from the blueprints and BIM on site.
- Communication and request for information (RFI) between design consultants and construction practitioners
- Live communication through video chat between site and office
- Operation and maintenance management

STRENGTHS OF USING TABLETS

Tablets provide an easy access to up-to-date PDF/DWG drawings and BIM at meetings, in the office and out in the field. This reduce the risk of errors and rework due to old drawings. It is less time consuming to obtain necessary information like heights and measurements in the field through drawings and BIM at the tablet, instead of walking back to the site office and search through stacks of paper to find the required information in the office. Tablets also provide access to information about the progression of tasks and distribution of responsibilities. Much time is spent on delegate, follow up and ensure that things have been done. Through tablets, the workers at the site will receive personal tasks and responsibilities which they mark as finished when the task is done. This is an easy way to keep track of the progress of the project and reduce time spent on monitoring tasks and responsibilities.

A tablet contains hundreds of drawings and is easy to carry around compared to stacks of paper. It also reduces the stacks of paper stored at the site office, and time spent on printing and distributing hundreds of drawings. A reduction of paper consumption will also provide environmental gains. Large and heavy laptops have been used on construction sites to access the BIM out in the field. These laptops are dependent on a mouse to navigate in the model, which reduce the mobility of the user even more.Tablets are small, light and it is easy to navigate without using a mouse.

When tablets are used at site meetings, they provide easy access to a huge amount of up-to-date information and lead to faster decision making. Another strength is that tablets provide easy access to email and the ability to share screenshots of drawings in real-time at the construction site. The camera function also allows for taking photos of issues in the field for instantly sharing with a supervisor or consultant. An interviewee was especially pleased with that ability:*"Before, when I called the consultants, it took me five minutes just to explain where the problem was. Now I can take a picture, link it to a specific drawing and send it to the consultants, before calling him up. So much easier."*This enables faster decision-making processes, and facilitates decision making in the field.

With a BIM application it is possible to combine 2D drawings and 3D models. This is of great value. Through 3D models, it is possible to see a realistic environment with how things are connected, and then study details with 2D drawings. This increases the understanding of what to build.

By use of tablets, less time is spent on routine and administrative work. In quality assurance work and safety inspections tablets particularly facilitates preparations and complementary work. Based on interviews, it is created a table to compare a traditional process to a process using tablets.

Table 1: Traditional vs. tablet process of safety inspections

Where	Traditional process	Tablet process
Site office	Gather updated list of documents and plans Find current lists of issue Print documents and lists	Sync the software and get all updated documents and lists of issues on the tablet
Field	Mark issues one-by-one on the paper plan Take photos Handwrite notes on paper	Create multiple issues Make notes on the tablet Attach photos directly to the issue
Site office	Scan the marked up plan Type field notes into the computer Paste digital photos Manually pull together all lists Print or email report for others	Sync the software to pull together all lists Print or email report

As exemplified above, use of tablets simplifies the documentation process. This leads to a higher quality of the documentation, due to a standardization of the process. All communication through tablets is traceable and it is therefore easy to prove that things have been done in a transparent way.

When a worker in the field has a request for information, the traditional process is to walk to the site office, mark the problem area at the paper drawing, scan the drawing, send an email to the consultant, and walk back. According to internal documents from the contractor Veidekke, this process takes in average 20 minutes. Using a tablet, the worker can mark the problem area directly on the tablet and send the email, without leaving the workplace. New revisions of the drawings can also be received directly in the field instead of walking back to the site office and printing out new copies. Hence, tablets reduce the amount of unnecessary movements. Another strength is that tablets provide an easier access to direct communication between foremen and design consultants, as the exchange of the information don't have to go through the construction manager or the project manager. This provides a more efficient line of communication. It is however very important that such communication is visible to the supervisors.

CHALLENGES OF USING TABLETS

It is a challenge to defend the cost / benefit ratio of the tablets in the initial introduction. This is because it may take years before documented benefits exceeds the cons, as there are many complex connections to take into consideration. In addition to the cost of the tablets, BIM applications also incur costs. It is a spread in how user-friendly the applications are, and they often require guidance and training in the initial phase. In the initial introduction, it is also a challenge that experienced craftsmen have poor motivation to learn a new tool and change the way they work. In addition to the challenge of learning a new tool, some craftsmen get the feeling that the BIM is only developed for design purposes. It is often incomplete and not usable at the construction site. An interviewee explained that many craftsmen also find it difficult to trust the correctness of measurements in the BIM.: *"Objects where often placed a few cm wrong, and it is a lot harder to spot these small errors in a 3D model, than in 2D drawings. When this happen several times, you find it hard to trust the BIM."*

It is necessary to have network access to synchronize the tablets. Without network in the field, the craftsmen have to walk back to the site office to update the drawings and send emails. This can be a challenge on construction sites outside the city and in basements below ground, where there is usually limited access to 3G or 4G.

The tablets are easy to carry around, but they are also easy to lose or misplace. Without a secure password or a remote erase program, this can lead to reduced data security and that outsiders can get access to sensitive project information.

Tablets works poorly when there is precipitation or dust. Without protection, the tablet is thereforedifficultto use during the concrete work and before the building is tight, because of weather, concrete dust and moisture.

Some applications often support only one operating system. This is a challenge when stakeholders often have deals and agreements with different operation systems, which can prevent them from using the system required.

INITIATIVES WHICH CAN LEAD TO A BETTER UTILIZATION OF TABLETS

Several initiatives can reinforce the benefits and reduce the challenges of using tablets as a mean to communicate between design and construction practitioners.

To be able to defend the cost/benefit ratio in the initial introduction, it is important to promote success stories. Ambassadors should show the construction industry what potential benefits the initial costs can provide. It is also possible to start with a small scale pilot project to test the effect, and spread experiences to the rest of the company once the benefits are proven. Some craftsmen have poor motivation to learn new tools and change the way they work, and it is important to change their attitude. This can be handled by involving craftsmen in decisions during the initial introduction. It is also important to give sufficient guidance and training in this phase to enhance their confidence in using tablets.The BIM should be more trustworthy and useful in the field. This requires that the BIM is modelled for its purpose, and that the right level of detail, constructability and usability of the model is assessed. This may increase the craftsmen's trust in the model.

Table 2: Strengths and challenges

Strengths	Challenges
Easy access to information	Cost/benefit ratio
Reduce the risk of errors due to old drawings	Poor motivation amongst craftsmen
Less printing and distributing drawings	Poor usability of the BIM
Environmental gains	Lack of trust in the BIM
Easy to carry around	Dependent on network
Reduce time on monitoring and reporting	Reduced data security
Increases the understanding of what to build	Vulnerable to moisture and dust
Faster decision-making processes	Lack of support of operating systems
Improved documentation and reports	
Reducing unnecessary movements	
Creates a new line of communication	

The applications should support all operating systems, to make sure that all stakeholders can use it. There should also be several functions integrated into one application, to enhance the efficiency of the tablets and reduce the number of applications. Having only a single platform will reduce time spent on looking for information, and improve the construction information management

To meet the dependency of network at the site, it is suggested to install a dedicated network at the construction site. This will guarantee accessto up-to-date information throughout the site without having to walk to the office to synchronize the tablet. It is also possible to reduce the dependency of network at the site with an offline mode in the applications. This allows for obtaining information without access to network. However, this will not be up-to-date information.

There should be used waterproof tablets or protection against moist, sand, vibrations and concrete dust to reduce the chance of tablets being destroyed due to precipitation or moisture at the construction site. This will increase the possibility of using the tablet throughout the construction phase, including the concrete period. When a tablet is misplaced or stolen, there should be a routine to remote erase all content on the tablet. This is to prevent outsiders from gaining access to sensitive information.

Table 3: Initiatives

Initiatives which can lead to a better utilization of tablets
Promote success stories
Pilot projects
Guidance and training
Assess usability throughout the development of BIM
Install network at the construction site
Offline mode
Remote erase routine
Several functions integrated in one application
Develop applications which support all operating systems
Waterproof tablets and other protection

CONCLUSION

This study can potentially give practitioners and researchers new knowledge of the strengths/challenges of using tablets on a construction site. Initiatives to reinforce the strengths and reduce the challenges have also been proposed. These initiatives require cooperation between designers, construction practitioners and system developers. Installation of a dedicated network at construction sitesoutside the city is an important initiative because many of the features are entirely dependent on updated information. However, this leads to higher costs and can be especially difficult on major road constructions where the site covers several kilometres. Guidance and training to enhance craftsmen’s confidence in using tablets will also incur costs. It is therefore crucial to have ambassadors promoting success stories, and show the construction industry what potential benefits these initial costs can provide. In order to exploit the benefits BIM can bring to the construction site, it is important to assess usability and constructability throughout the development of the model. Tables 4 and 5 sum up what initiatives that can reinforce the strengths and what initiatives can reduce challenges of using tablets.

Table 4: Strengths and initiatives to reinforce them (not prioritized)

Strengths	Initiatives to reinforce the strengths
Easy access to information	Install network, offline mode, several functions integrated into one application
Reduce errors due to old drawings	Install network to ensure updated information
Less printing and distributing paper	
Environmental gains	
Easy to carry around	Waterproof tablets and other protection
Reduce time spent on monitoring tasks	Several functions in the applications
Increases the understanding	Assess usability in the development of BIM
Faster decision-making processes	Install network at the construction site
Reduce time spent on reporting	Several functions in the applications
Improves documentation and reports	
Reduce unnecessary movements	Install network at the construction site
Creates a new line of communication	

Table 5: Challenges and initiatives to reduce them

Challenges	Initiatives to reduce the challenges
Cost/benefit ratio	Promoting success stories, pilot projects
Poor motivation amongst craftsmen	Guidance and training
Poor usability of the BIM	Assess usability in the development of BIM
Lack of trust in the BIM	Assess usability in the development of BIM
Dependent on network	Install network, offline mode
Reduce data security	Remote erase routine
Vulnerable to moisture and dust	Waterproof tablets and other protection
Applications does not support all operating systems	Extend the application's support for all operating systems

To conclude, it can be said that application of tablets will improve information management in construction projects. At the same time, the proposed initiatives will help to improve the benefit/cost ratio of an initial introduction of tablets. The research is based on a limited number of respondents and it is conducted in a Norwegian context. This may not make the results 100 % applicable to all projects. In the future there should be conducted experiments to get a more systematic view of the net benefits of using tablets. A cost benefit analysis of tablets compared to a manual approach should also be conducted.

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TEACHING LEAN CONSTRUCTION

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LEAN SIMULATION IN ROAD CONSTRUCTION: TEACHING OF BASIC LEAN PRINCIPALS

Jakob von Heyl[1]

ABSTRACT

Since the first adaption of lean management to the building sector, numerous principals, methods and tools have been successfully adapted, developed and implemented and the term Lean Construction has been coined. However, Lean Construction is often only partially or incorrectly applied. A basic cause is that site management and workers are not familiar with Lean Construction, therefore only reluctantly applying lean methods and tools. But successful application of Lean Construction requires a holistic and determined approach with convinced project participants. Thus a systematic approach to teach basic lean principals and tools is crucial for the acceptance and application of Lean Construction.

In this paper a developed simulation game is depicted. A road construction site and its logistics are simulated. In the round based game a logistic chain and the operating grade of a finishing machine are getting optimized. First the traditional planning and execution of the site with its limitations and characteristics are simulated. Afterwards the participants discuss possible improvements. Then the site is simulated once more, this time using lean principles and an active management of bottlenecks. The gained improvements in productivity are examined by the participants and the lessons learnt are described.

KEYWORDS

Lean construction, action learning, logistics, kanban, flow, collaboration.

INTRODUCTION

Many construction companies suffer from inefficiency and operational problems at their construction sites. Approaches like Lean Construction are increasingly applied in order to improve the productivity and thus the profit margin. In Germany Lean Construction has been successfully implemented in many projects but it proves to be a continuing challenge to secure the improvements made and to qualify staff.

A road construction site is highly dependent on a steady supply of material. The application of lean principles can help to decrease the work flow variability in order to improve efficiency (Tommelein, Riley and Howell, 1999). Several road

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construction projects in Germany have been improved successfully using lean principles (e.g. L611 Bauschlott, B466 Neresheim or A8 Hohberg – Enztal (Mayer, 2009)). In order to apply lean principles the use of simulations can be beneficial to optimize planning and production processes. Particularly the logistics can be examined well with simulations in order to improve reliability and efficiency of manufacturing processes (Berner et al., 2013).

An important aim of road construction companies applying lean construction is the dissemination and the transfer of lean principles and lessons learnt to their work staff (Mayer, 2009). Simulation games are seen as an important supplemental tool for teaching leans principles and methods (Choomlucksana, 2013). This paper describes a simulation game developed on the basis of the lessons learnt from several optimization projects dealing with supply chains at road construction sites. Sticking points are central planning and management as well as implementing a continuous flow through cycle times and kanban cards.

LEAN MANAGEMENT IN ROAD CONSTRUCTION

OPERATIONAL CHALLENGES

Construction sites still offer a significant potential for improvements. A very promising working point for the improvement of many road construction sites or earthworks is the logistics (Gehbauer, Koskela and Kirchbach, 2014).

At road construction sites the supply chain between the mixing plant and the finisher is often unreliable and inefficient. Traffic, insufficient planning, inexperienced drivers and untuned processes disturb the continuous flow and lead to pack forming of the trucks. An integral logistics planning often doesn't take place. Furthermore it is quite common that the tasks within the logistics management are indefinite. At many road construction sites possible bottlenecks are not consequently identified and eliminated in advance, so rescheduling is required during construction. At the same time insufficient planning of the internal and external resources takes place. As a consequence construction managers have to deal with unreliable schedules, insufficient supply and troubleshooting. That all causes mistakes and a waste of resources (muda). The trucks, the mixing plant and the finisher are often not used up to their potential. An analysis showed that the trucks were standing idle in average 50% of their cycle time (Kaiser and Zikas, 2009).

OPTIMIZATION APPROACHES

The following optimization measures were carried out at several road construction sites. The finisher was identified as the most important factor in the production process. Therefore all processes were aligned to the finisher in order to enable an uninterrupted production. At first the production capacity of the finisher was identified, after that the required resources (type and quantity) were determined. The steady supply of the construction site is crucial for an uninterrupted construction activity. A formula was developed to determine the required amount of trucks at a road construction site.

$$\text{Amount of trucks} = \frac{P \times T \times S}{C}$$

Performance finisher	= P [t/sec]
Circulation time	= T [sec]
Capacity of truck	= C [t/truck]
Safety factor	= S [-]

Figure 1: Formula to determine required amount of trucks

The required amount is calculated based on the performance of the finisher. The capacity of the trucks and the safety factor are empirical values. The cycle time of the truck has to be determined in trials for each project. The definition of a sequence of the trucks stabilizes the supply chain. The routes of the trucks are planned and managed centrally. So are the delivery, breaking and tanking times of each truck. A cycle time was defined aligned to the capacity of the finisher. This made it possible to establish a continuous flow. Kanban cards were introduced to ensure that the truck drivers complied with the specifications (routes, times and standards). Due to the measures described above, the supply chain could be stabilized. As can be seen from the figure 2, a stable and steady supply of the finisher was realized.

A less interrupted delivery of material reduced the waiting times of the finisher and trucks and the output of the finisher went up from 182 t/h to 302 t/h. Thus an improvement of the performance by approximately 66% was realized (Kaiser and Zikas, 2009).

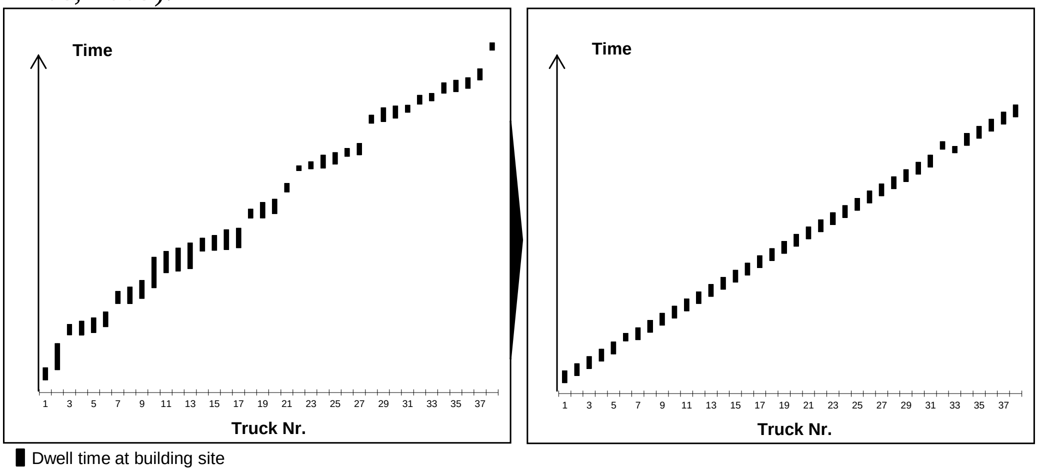

Figure 2: Stable supply chain after implementing cycle time and continuous flow

SIMULATION GAME

BACKGROUND ON TEACHING / SIMULATION GAMES

Teaching Lean Construction is not trivial as abstract concepts as well as specific approaches and terms have to be taught. Therefore a professional approach is required (Pellicer and Ponz-Tienda, 2014). The probability of memorizing information increases with the number of temporal, spatial and semantic relationships that are developed between the contents. Furthermore emotions and existing knowledge have a great influence (Donovan, 2007). The most promising teaching methods encourage learners to independently practice and reflect contents. A connection with the professional and personal situation of learners can accelerate the learning process significantly (Bransford, Brown and Cocking, 2003). Consequently, action and person-oriented teaching is desirable to impart action competence. Action competence refers to the ability to deal independently with situations. Situations are characterized by the accumulation of obstacles that hamper goal fulfillment. These obstacles should be tackled while the overall solution is taken into account. The action competence can be further distinguished by hierarchy as shown in figure 3 (Ott, 2000).

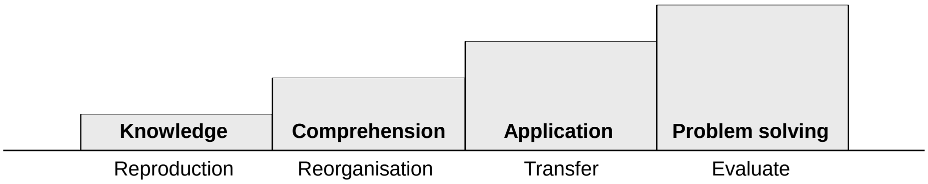

Figure 3: Hierarchy of action competence according to Ott

Simulation games are an appropriate method to improve action competence as they simplify a complex real world problem to its essential structure in order to teach techniques, skills and competences. Based on the game, the student is introduced to a topic or problem and is asked to independently find an approach to the problem. This promotes his autonomy and decision-making skills. The participants are involved very actively and encouraged to practice and reflect the contents taught. The simulation game in this paper addresses professionals and focuses on self-directed and autonomous learning. To teach Lean Construction using simulation games is not a new approach. Several games have already been successfully developed to impart lean principles (e.g. LEBSCO (González et al., 2015), LEAPCON (Sacks, 2007) or the Lean Hospital Game (Dukovska-Popovska, Hove-Madsen and Nielsen, 2008)).

ADDRESSED CHARACTERISTICS / DEPICTED CONTENTS

As shown before the logistics are a very important factor of a road construction site - a functioning supply chain contributes to more reliability and more efficiency. It is intended to simulate a traditional road construction site and its supply chain with its typical framework and challenges.

Table 1: Simulated Framework and Challenges of road construction sites

Framework	Challenges
Long supply routes	Pack forming of trucks
Limited buffer size at mixing plant and road construction site	Tendency to individual optimization instead of integral optimization
Material requires a minimum temperature	Mutual obstruction of trucks
Restricted working and driving times	Lack of coordination (breaks, routes etc.)
Required preparatory work and rework	Machine failure
Machinery supply and maintenance	Challenges maneuvering the trucks
Limited production capacity of finisher and mixing plant	Changing traffic density

Subsequently the participants have to optimize the supply chain between a mixing plant and a finisher similarly to the optimization approaches depicted above. Central planning and management is introduced in order to increase the output and to optimize the use of resources.

GAMEPLAY

Like other simulation games (e.g. LEBSCO (González et al., 2015)) the game consists of two rounds. First a traditional road construction site with its typical framework and challenges is simulated. In the second round optimizations are introduced, with certain aspects of the game being pre-set. Thus the sequence of the game is the following:

- Step 1: Introduction and explanation of basic lean principles.
- Step 2: 1st round.
- Step 3: Analysis and discussion.
- Step 4: 2nd round.
- *Step 5: Analysis*, discussion and feedback.

Before the simulation can be carried out, the various roles of the game (e.g. truck driver, mixing plant worker, construction site worker) are assigned to the participants. Subsequently, the principles and rules of the simulation are explained. It is crucial that all participants understand their individual role and tasks. To ensure that all rules and tasks were correctly received and understood, test runs are recommended before the first round of simulation is carried out.

After completion of the first round subjective impressions are queried and discussed. KPIs are identified and the construction process gets evaluated, using provided forms. Now possible improvements are worked out in groups. The Game master complements the suggestions and proposes an optimization procedure inspired by the optimization approaches described above. Subsequently the participants calculate the required amount of trucks and implement the process improvements in order to eliminate waiting times and to optimize the use of resources. Now the second round gets carried out. Possible improvements that have been worked out at step 3 are taken into account. Reducing the amount of trucks and establishing a continuous flow with kanban cards out improves the reliability of supply. Hence the transport cycles are shorter, resources are used in a more efficient way and fewer batches are damaged. The figure 4 exemplifies the realized reduction of waiting time.

Afterwards the second round gets evaluated. Again the participants are working in groups to think of further possible improvements. Each group presents their ideas and tries to apply the learnt principles to the construction sites that they are currently dealing with. Finally the participants give their feedback on the simulation game.

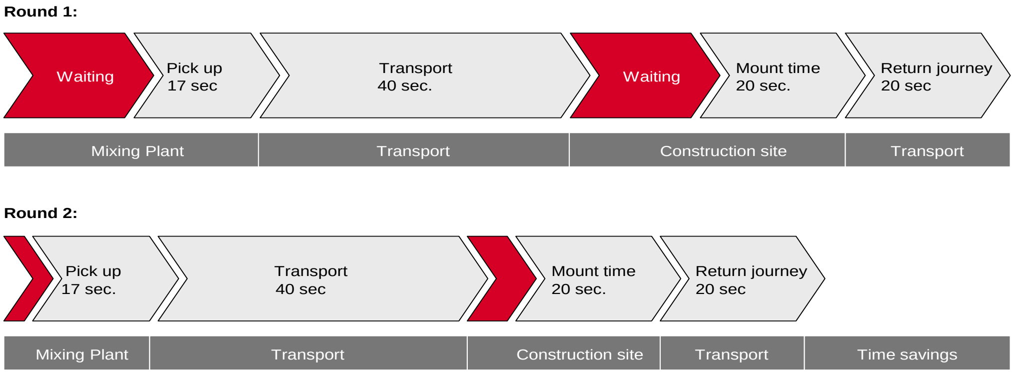

Figure 4: Shorter transport cycles in round 2

GAME ROLES

The game has different roles with specific tasks and purposes as listed in the table below. Each game participant receives a role. At least 12 players are required for the different roles and tasks.

Table 2: Game roles

Role	Pers.	Task / Purpose
Truck driver	8	Remote control of trucks; transport and unload of asphalt batches
Mixing plant	2	Operation of marble run and silo; measuring downtimes; responsible for delivery notes (log up and handing over)
Site worker	1	Acceptance of asphalt batches and delivery notes; responsible for asphalt paving; documentation of delivery notes; sort out defective material; measuring downtimes
Observer	>0	Observing the gameplay; documentation of interesting incidents; ensuring compliance with rules of the game
Game Master	1	Introduction and explanation of roles, rules, gameplay and game elements; ensuring compliance with rules of the game; play of gameplay cards; moderation and control

GAME ELEMENTS

The following elements of the supply chain are simulated: means of transport, mixture, mixing plant, construction site with finisher, resting area and the possible routes. In addition, a central timer, stopwatches, several cards (gameplay and kanban) and form sheets are necessary.

The asphalt batches (mixture) are symbolized by 50 wood cuboids – a cuboid fits into a miniature truck. If transportation time exceeds 120 seconds the asphalt batches are considered to be too cold and therefore are declared as damaged goods. Asphalt batches are delivered with a delivery note. This note also contains information that needs to be registered by the participants.

A central timer shows the current time of the game. In addition the participants that are responsible for the mixing plant or the construction site get a stopwatch to measure downtime (muda). Eight remote-controlled and numbered miniature trucks are used as means of transport. The mixing plant is simulated with a marble run and a slide. The throughput time of the marble run symbolizes the required time for a mixing process. The slide can hold four asphalt batches and symbolizes the silos (buffer). After the marble ran through the marble run, an asphalt batch can be put on the slide. Only if the slide contains less than four batches the mixing process can be executed. The trucks pick up the batches from the slide as illustrated in the figure 6.

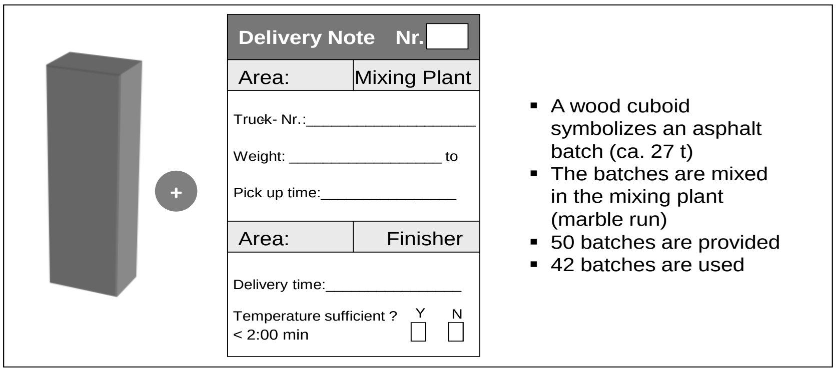

Figure 5: Wood cuboids and delivery notes

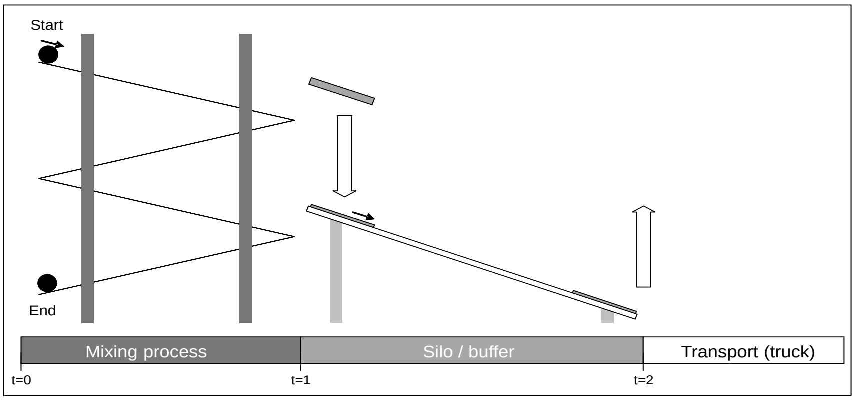

Figure 6: Mixing plant

The construction site and the finisher are symbolized by a wooden track with markings to show the construction progress. In addition, areas for the delivery notes and damaged asphalt batches as well as a delivery zone for the trucks are indicated. Once the truck arrives, the asphalt batch and the delivery note are accepted if the delivery time doesn't exceed 120 seconds. If the delivery time exceeds 120 seconds, the batch is declared as damaged good and can't be used anymore. The successive deposition of the asphalt batches on the wooden track simulates the construction process.

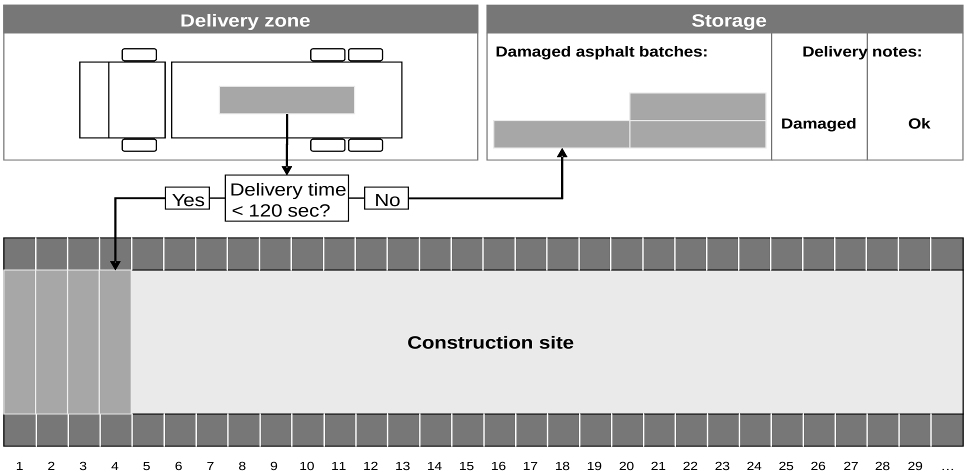

Figure 7: Construction site

The participants can follow different courses, which are staked out with small gateways. The gateways have to be passed in a certain sequence. The course is divided into four routes: Three routes of different length from the mixing plant to the construction site and one from the construction site to the mixing plant.

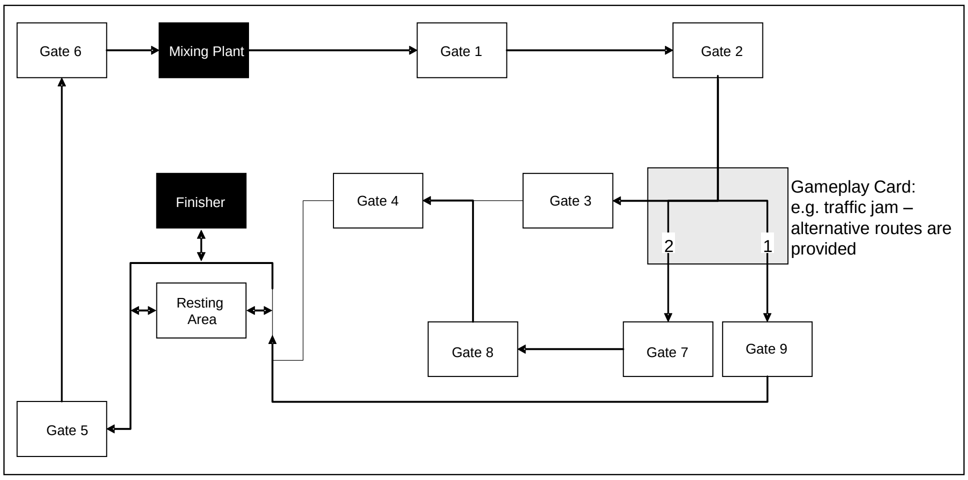

Figure 8: Course between the mixing plant and the construction site

The resting and refuelling of the trucks has to be done in the resting area. Each truck-driver has to rest at least once for 90 seconds – the resting times are registered. To simulate the refuelling process a form needs to be filled out – the required time symbolizes the time spent at the gas station. During the game certain events, e.g. traffic jam or police controls are simulated (gameplay cards). At first the routes are freely selectable whereas in the second round the shortest route or an alternative route in case of traffic jams or police controls is set. Like that the positive effects of a systematic route planning and global optimization can be demonstrated.

At the beginning of the second round the required amount of trucks is calculated. The resource allocation is optimized and kanban cards are now introduced in order to define a specific rhythm for each truck.

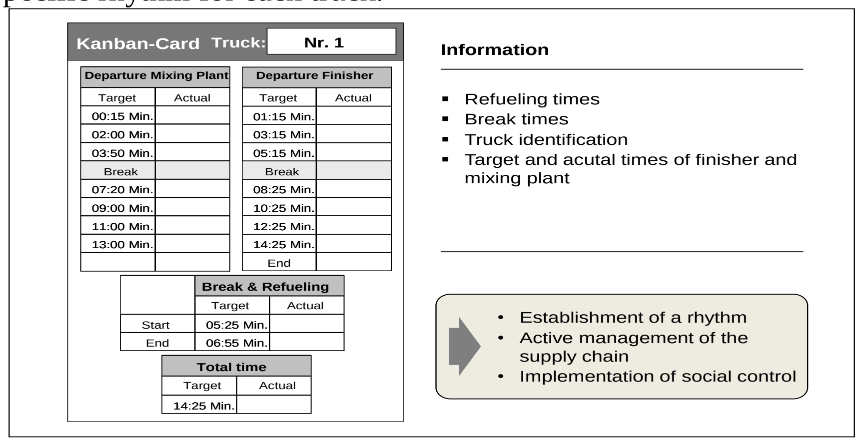

Figure 9: Kanban-Cards

The times when the batch is picked up and delivered as well as the breaking and refuelling points are pre-set. In order to detect deviations the actual times of the trucks have to be registered in the kanban cards.

Very important for the learning effect is that the use of resources and important process times are documented after each round. At the end of the simulation the figures can be compared and improvements are made visible.

EVALUATION

The game got tested in a test run with interns at a consulting company in Germany. The assessment of the participants was queried and data got collected. The test run showed that the basic framework and challenges of a road construction site were simulated successfully. The connections made with the personal situation and knowledge of the participants facilitates the learning process. It was possible to involve the participants actively with all sensory channels. The play-like character and the practical relevance of the training helped to motivate the participants. They got encouraged to give lean principles a try and to excogitate about existing processes and possible improvements. In the following table the KPIs of both rounds are compared.

Table 3: KPIs of the trial run

KPI	1st Round	2nd Round	Difference
Trucks	8	6	-25%
Waiting time mixing plant	~ 180 sec	~ 60 sec	-66%
Waiting time construction site	0 sec	~ 20 sec	+100%
Built in asphalt batches	30	42	+40%
Damaged asphalt batches	15	0	-100%
Scrap	33,3%	0%	-100%

The improvements made from the 1st to the 2nd round demonstrate the potentials of Lean Construction. The apparent improvement is expected to inspire the participants to try Lean Construction at their own construction site.

CONCLUSIONS

Lean Construction is a promising approach to improve productivity in the road construction sector. Lean principles have been successfully applied to optimize the processes in companies and projects. Training is a relevant part of sustainably implementing Lean Construction. Simulation games are very suitable to impart lean principles and prove to be an important supplemental tool for teaching.

The test run of the developed simulation game was successful. The framework and challenges of a supply chain of a road construction site were successfully simulated. The participants implemented lean principles and improvements were realised. It was possible to demonstrate the positive effects of Lean Construction. The feedback of the participants in the test run was positive. Thus it is believed that the simulation game is a useful tool to improve the action competence in the field of Lean Construction. Further test runs are recommended in order to improve and fine tune the game. Once this is done it is conceivable to use the simulation game professionally.

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BRINGING LEAN CONSTRUCTION TO LIFE: DEVELOPING LEADERS, CONSULTANTS, COACHES, FACILITATORS, TRAINERS & INSTRUCTORS.

Alan Mossman[1]

ABSTRACT

There is a global shortage of competent and experienced individuals able to lead, coach, facilitate, train and provide consultancy support both internally and externally to clients, owners, constructors and designers who want to make a successful lean transformation of their enterprise or their projects. Demand exists within public and private sector clients and owners, as well as among design and construction enterprises and their professional advisers.

If the shortage is not addressed there is the potential for the advance of lean thinking in construction to stall and lean construction to get a bad name as constructors and others seek to cut corners and pay lip service to lean as happened in UK (United Kingdom) 15 years ago.

The aim of this paper is to begin a discussion of the skills and knowledge required by those who want to succeed in one or more of these roles.

This essay reviews past lean construction leadership development actions and suggests a curriculum for those who want to develop the skills and knowledge required to excel in these roles.

A delivery framework for a development program is proposed.

The paper concludes with calls for further research and for action sooner rather than later to address the issues, preferably on a regional or global level rather than on a national one.

The value of the paper for practitioners is that it suggests the range of skills and knowledge required to be effective which can help their own development and help assess and recruit internal and external consultants, etc; the benefit for scholars is the discussion of what might be included in undergraduate and higher degree curricula as well as ideas for post-experience, post-graduate course offerings aimed at this need.

KEYWORDS

Lean Construction, leadership, consultancy, coaching, facilitation, training, instructing.

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INTRODUCTION

The number of design and construction organisations that want to apply lean thinking to their operations and their projects is increasing. The growth in interest in Lean construction is evidenced for example by growth in submissions to this conference, growth in corporate members of LCI (Lean Construction Institute) and P^2SL (Project and Production Systems Lab, UC Berkeley) and individual members of lean construction groups on LinkedIn. A consequence of this growth is that there is now a shortage of skilled and competent individuals to support the growing demand for help with lean transformation at the enterprise and at the project level. This is as true for the US (based on conversations with a number of American lean leaders) as it is elsewhere in the world.

Failure to address this shortage could stall the advance of lean thinking in construction, as happened in UK 15 years ago (Mossman, 2008), and give lean construction a bad name as constructors and others seek to cut corners and pay lip-service to the ideas.

A critical problem is that much of the knowledge is *tacit* rather than explicit. Tacit knowledge includes ways of knowing, being & doing that often we are unaware that we know. You can probably ride a bike but can you describe how you do it? How you do it is a classic example of tacit knowledge.

Many pioneer companies are clustered intellectually, and often physically, around UC Berkeley in California. Even for them, much of the learning and leadership development has been self-directed. A notable exception was the Shusa program developed by Greg Howell and Hal Macomber in the early 2000s – a course of simulations, directed reading and discussion – attended by many of the US pioneers.

The intention of this paper is to begin a discussion about how to systematically develop a worldwide cadre of individuals with the skills and knowledge to operate effectively in a design, construction or facility management environment.

WHAT SKILLS AND KNOWLEDGE ARE REQUIRED?

In his presentation to the first Indian Lean Construction Conference (Mumbai, Feb 2015) Glenn Ballard defined lean construction as "a management philosophy defined by the *ideal* it pursues, the *principles* it follows in pursuit of the ideal and the *methods* used to implement them". In the paper accompanying his presentation he wrote: *The lean ideal: Provide customers, internal and external, with what they need, with no waste.* (Ballard, 2015)

Being a lean construction consultant, facilitator, coach, trainer, instructor requires:

some knowledge, appreciation & understanding of:

- big room/co-location
- construction & design
- Last Planner® & RbPS
- lean project delivery
- lean thinking and flow
- learning & theory of knowledge

some knowledge, appreciation & understanding of, *and skills in*:

- Choosing By Advantages (CBA)
- coaching
- consultancy
- decision making
- facilitation
- leadership, including servant

- pre-fabrication
- production theory
- psychology
- systems
- target value design (TVD)
- Training within Industry (TWI)
- Variation

leadership

- managing change
- personal and organizational learning
- process mapping
- production planning and management
- reliable promising
- running simulations
- training & instructing

The expression "some knowledge, appreciation and understanding …" is used in the sense that "one need not be eminent in any nor in all the parts in order to understand and apply it." (Deming, 1994, 93 referring to the *System of Profound Knowledge)*

SOURCES OF CANDIDATES

Pioneers have come from a variety of backgrounds including construction, design, lean manufacturing, lean consultancy, management consultancy, training. All had some of the skills and knowledge listed above and, to be effective, each needed some of the skills and knowledge of all the others.

Those who tell me they are interested in learning to lead, coach, facilitate, train and provide lean construction consultancy come from an equally diverse range of backgrounds including construction, design, lean consultancy, management consultancy, training.

HAS THE ISSUE BEEN ADDRESSED BEFORE?

So far as I know there has been one formal attempt to do this before – The *Lean Project Leadership (Shusa[2]) Program* offered in 2003 by Lean Project Consulting, Inc. and The Center for Innovation in Project and Production Management (LCI US).

The Shusa program "*develops leaders able to implement lean projects and teach the essential practices and habits of mind to others*" (Howell, 2006) and consisted of:

- 6 face to face sessions (1800 Monday - 1415 Wednesday) over 5 months
- weekly Study-Action Team meetings (Slivon and Macomber, 2010)
- 2 x coaching relationships with other participants
- Action learning based around a project at work (e.g. Revans, 1980)
- preparing a 3-5 page white paper on a related topic
- developing a personal learning plan for continuing development.

The face-to-face sessions session began …"with a simulation or game chosen to explore some aspect of lean delivery. Participants conduct these exercises to gain experience with the game and managing discussions. We place an emphasis on learning with others while in action -- Study Action Teams. The remainder of each

[2] Shusa is the Japanese term for respected leader and is particularly applied to leaders of large projects

session includes a combination of large and small group discussions on the books, book summaries, and articles assigned as homework. Ten books have been chosen for the program based on their historical, technical, and leadership content. A similar number of book summaries and articles are also assigned drawn from a variety of sources. Study-Action Teams work together by phone in the periods between meetings as well.

Part of each session is devoted to specific aspects of lean project delivery and the Last Planner System™ (LPS). Short lectures introduce some topics but the emphasis is on being in action. Most participants will be managing a project using LPS and these will be the subject of reflection and discussion.

Each participant will be involved in two coaching relationships with other participants as a coach and a "coachee" …. Coaching is a continuing subject. Participants will engage with experts, other practitioners, and as experts for developing their skills and a personal body of knowledge.

Each participant will draft and present a white paper (3-5 pages) on a related topic and participate as appropriate in a continuing web-based discussion. The program closes with the development of an individual learning plan for each participant. (Howell, 2006)

Participants in the second Shusa program included individuals from DPR, LeanTrak, Boldt (2), Messer Construction (3) & Linbeck. At least one is now retired.

There is one other important source of leaders in our community, the UC Berkeley Doctoral & Masters program led by Profs Glenn Ballard and Iris Tommellein. Some graduates have remained in the academic world and provide leadership there while others have gone on to lead in commercial settings.

CORPORATE PROGRAMS

Some larger companies have set up their own internal programs – e.g. Granya y Montero, JE Dunn, Shepherd, Alstom, CH2M. Some are more formal than others.

THE QUALIFIED PROJECT STEWARD (QPS) TRAINING PROGRAM

In 2011 CH2M advertised for Project Stewards (PS) to support design teams detailing the background and experience of candidates they sought as:

- Design and construction industry background
- Registered engineer/architect, minimum 5 years experience
- Technical design discipline leadership and project leadership experience
- Knowledge and experience in managing multidiscipline design integration, interdependencies, and system level relationships
- Demonstrated leadership skill with emphasis on cross-discipline coordination (e.g. project engineer, project architect, design manager, or similar role)
- Leadership and facilitation of large group meetings and working sessions
- General Management with lean practice backgrounds and demonstrated skills will be considered
- Experience with lean design and construction practices is beneficial (e.g. LPS)

The advert described successful *Project Stewards* (PSs) as:

- **Responsible**: …. A PS assumes responsibility for the team's adoption of RbPD [Macomber and Bettler 2011] and practice of it. A good PS thrives on … responsibility that comes without power.
- **Humble**: A humble PS is willing to do what is necessary to help the team achieve its goal recognizing that his or her success is found in the team's success. He or she recognizes the value in each team member, and by example leads others to the same appreciation.
- **Collaborative**: A good PS will work to ensure a collaborative culture exists within the team. The PS ensures team members feel able and supported in raising issues for open discussion. A good PS will establish collaboration as the team norm and will coach for appropriate behavior.
- **Committed**: The PS role requires someone in the role who is fully committed to it. The PS must feel the same high level of commitment to the project and its goals as do team members. Further, we seek candidates who are willing to commit to 1 or 2 or more years in the role to develop deep expertise and the capacity to teach the role to others.
- **Influential**: To be successful a PS will need to influence the team and the organization. Initially, team members may need to be influenced to begin to practice RbPD or to improve collaboration. A PS should know how to exert influence without resorting to a command and control style.
- **Knowledgeable**: The best PSs have the technical, industry, market, or specific knowledge to help the team in pursuit of its goal. (CH2M, 2011)

CH2M listed the skills of successful *Project Stewards* as including:

- Facilitation
- Listening
- Make assessments
- Quick thinking
- Making & securing reliable promises
- Excellent communication – written & verbal
- Organization & planning
- Coaching
- Adapting and responding to dynamic situations
- Ability and desire to master new skills
- Open learner – enjoys learning-while-doing in front of others.
- Highly coachable (CH2M, 2011)

How were the successful applicants going to learn all this *stuff*? They became part of a Community of Practice (CoP) of CH2M *Project Steward*s and Project Coaches "working and learning together to lead projects for learning and improvement." In addition they were promised training and development:

- "Coaching from a CH2M Hill Project Coach who will provide training and real time coaching as you learn your new role
- Intensive hands-on Qualified Project Steward (QPS) training workshop together with other Project Stewards

- Coaching & practice learning the skills of ‘Leader as teacher’, Socratic method
- Develop improvisation skills; adapting to situations
- Develop deep insight into cross discipline interdependencies and dynamics
- Receive training and coaching in the skills of making and securing reliable promises
- Build relationships with the whole project team
- Build relationships with project and organization management
- Build skill in leading change and dealing with resistance
- Other training and developmental benefits
- Facilitation skills
- Leading groups
- Negotiation
- Root cause analysis –5Why
- Group problem solving
- Sound decisionmaking, Choosing by Advantages (CBA)
- Managing constraints on projects
- Being in service to the team - servant leadership” (CH2M, 2011)

Jeff Loeb, one of the internal lean coaches, reported the following results realised in the first two years of this program (personal communication):

- 16 Project Stewards (PS) were recruited (all of them internally) and completed the QPS training program. Each PS stewarded between 2 & 8 projects.
- 16 Project Managers and Operations Leaders also completed the QPS training enabling them to effectively partner with PSs.
- 3 CH2M internal lean coaches led the CoP, broadened lean capability within the organization, and supported the development of the Project Stewards.
- 36 design projects were delivered on a lean basis, each with a PS facilitating lean practices (with RbPD as a focus).
- Bi-weekly Lean CoP meetings enabled shared learning, peer coaching, and methods development. CoP participants included a mix of Project Managers, PSs, department leaders, and individuals desiring to practice lean.
- 50% more projects met or exceeded profitability targets.
- Performance against schedule improved incrementally, though with a marked decrease in ‘sprinting to the finish line’.
- Teams consistently reported higher engagement, less stress, and better whole-project understanding than on traditionally delivered projects.

Grana y Montero, a Peruvian constructor, has a unit called *The Academy* dedicated to managing the existing knowledge of group and also generating means for incorporating new knowledge through research and innovation. It is divided into three main schools – leadership and people management; project management and continuous operations; the technical school. For the last 15 years GyM has had a groupwide strategy to create each jobsite as a *place of learning*. GyM have 300 “internal teachers”, construction professionals who additionally share their roles and knowledge in the group (private communication with the author).

There has been no formal evaluation of any of these programs.

WHAT DO LEARNERS NEED?

Learners are likely to have degrees in a range of subjects and some will have higher degrees. All will have some years of work experience gathered in a range of settings.

The needs of each learner will be different and so it is difficult to specify a single curriculum that is appropriate to all possible learners.

Learners will want a program that is flexible enough to address their personal learning and skill development needs, rigorous in its approach and provides them with opportunities for continuing learning and development once the formal part of the program is complete. Some will want a qualification.

WHAT DOES A GROWING LEAN COMMUNITY NEED?

Owners, clients, designers, constructors and consultancies (+ universities and colleges) wishing to employ lean leaders, coaches, facilitators, instructors, trainers and/or consultants are likely to hire people who show evidence of the practical application of the broad range of skills, understandings and experience and of their continuing learning and development.

Many larger owners/clients, designers and constructors are multi-national in their operations. Specialists based in UK may work with Dutch architects and Australian builders on a project in the Middle-East while serving a variety of other projects in the UK and elsewhere in the world. The very inter-connected nature of contemporary design and construction suggests that developing a common set of ideas around the world will make it easier to form lean teams sharing a common language.

TOWARDS THE DESIGN OF A NEW PROGRAM

Criteria for the design:

- Flexible, learner-centred
- Multi-disciplinary
- Part-time,post-experience
- Develops people and process skills
- Built around live project(s)
- Involves the learner’s employer

These are very similar criteria to those that guided the design of the PG Diploma in Management by Self-Managed Learning (PGDip SML) at NE London Polytechnic[3] in the late 1970s. PGDip SML was the model for the Roffey Park MBA a decade later. It was also the basis for in-company programs (Mossman and Stewart 1987).

The PGDip SML was a two-year program run in the days before email and the web. *Self Managed Learning (SML) is an approach to management development which enables managers to be more aware of:*

[3] now the University of East London.

- how they achieve key results using live work issues...
- while controlling the content, processes and pace of their own learning...
- with a group of other managers who are collectively responsible for assessing their own progress ...
- within a structured programme facilitated by an Adviser.

The approach is based on a number of principles. These are expressed as an agreement between Learner and Set Adviser:

Learners:

- are responsible for their own learning
- have the right to and are responsible for identifying their own learning needs, and for changing them over time.
- have the right to and are responsible for negotiating how they meet their learning needs within the available learning resources.
- are responsible for evaluating and assessing their own learning.

Set Advisers:

- are responsible for helping the Learners realise their individual responsibility for their own learning.
- are responsible for providing access to the available learning resources
- have the right to and are responsible for determining their own personal involvement in the provision of learning resources (referral is acceptable).
- have the right to and are responsible for evaluating the whole programme and their own effectiveness.

These principles give rise to the process of Self Managed Learning through which the Learner personally works out what is to be learnt and how it is to be learnt, in conjunction with others." (Mossman and Stewart, 1987).

Throughout the program learners (who all came from around the London area) met every 2-3 weeks in groups of six with a *set adviser.* In the first three months learners developed *learning contracts* in which they outlined their personal curriculum for the remainder of the program. Learning contracts were negotiated with the learner's line manager, set and set advisor as well as the external examiner for the program.

During the middle section of the program (15 months) learners acted on their learning contract – frequently revising it (evidence of learning) in the light of their own learning and development. Learners used a wide variety of learning methods to support their own learning including Action Learning, action research, role play

In the final three months each learner presented evidence of their learning to their set in a powerful self-and-peer assessment process. Following the conclusion of the course many sets carried on working together on their continuing development.

DISCUSSION – TOWARDS A DELIVERY FRAMEWORK

The web, not available for the PGDip SML, and improved telephone services enable:

- sets to meet virtually on a more frequent basis
- peer coaching and consulting
- Study-Action Teams
- the program to draw learners from a much wider area.

The web will not replace face-to-face meetings:

- It is good to break bread together (as a number of IPD projects have discovered)
- Hanging out together in the bar or the coffee shop is vital for subsequent building of relationships online
- Simulations, a vital part of lean trainings, need to be experienced first so that facilitators have a sense of what their audience are experiencing.

The program differs from existing professionally-oriented built environment programs in a number of ways – it is, for example:

- **multi-disciplinary**—for integrated project teams and integrated project delivery requires built environment professionals who understand the languages of their fellow professionals and have the skills and knowledge to work effectively with them;
- **learner centred**—most program designers assume they know what students need to know; this program has a very different starting point that allows learners and their employers considerable freedom to define what they need;
- **develops people and process skills**—most existing programs are very good at developing technical skills. Technology most often fails because people and process issues are given insufficient consideration.

INITIAL IDEAS FOR THE PROGRAM:

This proposal envisages a number of universities collaborating to deliver a common program. Student enrolment will happen once a year or maybe once every other year.

When the course commences students will be allocated to a self-managed learning set and to a set advisor. Each student will also have a personal tutor in the university where they enrolled.

The program structure will have a number of elements:

- **Learning sets** – sets of five or six learners and a set-advisor (in a facilitative/consultative role) meet every 2-3 weeks on the web and occasionally face to face – this is where the learner reviews their project, their learning from their project and learns how to be a consultant to other learners; learners will learn vicariously from the experience of colleagues in their set. In the first weeks of the program each set will meet 2-3 times a week for an hour as a Study-Action Team™ (SAT) with two purposes:
  - To get to know each other
  - To build a shared picture of three key topics: lean, consultancy & facilitation
- **Residentials** – 2 per year of at least four days in each zone (Americas, Europe/Africa/Mid-East, Asia/Oceania) – six per year in total.

- **Learning contract** — each learner develops a learning contract with their set, their organisation and their mentor. A learning contract sets out a learner's unique learning program and is flexible enough to recognise that learning needs change and awareness of what you know and don't know changes too.
- **Learning Log** – learners keep a learning log as part of their reflective process
- **Communities of practice** – learners are expected to join at least one community of practice depending on their area(s) of interest and weakness
- **Webinars** – recorded and subsequently available to faculty and learners on the web – webinars will generally be presented twice to allow participation by learners in all time zones.
- **Libraries** — in and via the learner's university of registration
- **Workshops and courses** — in the learner's university of registration and in other cooperating institutions
- **Reports** – written and verbal, produced by the learner on their learning and on project progress, papers for IGLC, etc.
- **Self and peer assessment** of the learner's progress in the set.

Learners will graduate from their university of enrolment. Learners wanting to proceed to a masters will be expected to meet the dissertation regulations of their university of enrolment.

All the elements are tried and tested and have yet to be used together in this way.

The author has personal experience of most of them. He saw the power of the multi-disciplinary approach working with Shell Exploration and Production's P100 program that led a group of recent recruits from a wide range of disciplines through a team-based **action-learning** program; he served as a *set adviser* for 9 years on the pioneering PGDip SML and saw the impact of **learner-centred education** on the managers who participated–and the rigour of **self and peer assessment**; he has led **Study-Action Teams**™[4] and seen the ability of that process to build aspirations and excitement–one team he worked with was half a world away and connected via the web; recent and emerging technologies are making it ever easier to create distance learning experiences that make a difference *and allow people to have fun doing it.*

CONCLUSIONS

In order to support the growing interest in the application of lean thinking to design, construction and facility management in organisations and projects many more individuals each with a broad range of skills, knowledge and experience are required. The challenge is to find a way to develop those individuals.

The paper has presented an initial checklist of skills & knowledge required to lead a lean transformation, described a couple of previous attempts to do this and introduced an approach with the flexibility to meet the needs of both learners from diverse backgrounds and potential employers of those who complete the program.

A delivery framework has been briefly sketched.

[4] Study Action Team is a trademark of Lean Project Consulting. Leanproject.com

Action is now required to create a program or programs that will serve the needs of learners and organisations around the world and to clarify what will be required from providers.

FURTHER RESEARCH

A more systematic study of the skills, knowledge etc used by competent lean leaders, coaches, facilitators, instructors, trainers and/or consultants.

It would be useful to have an evaluation of:

- The Lean Project Leadership (Shusa) Program
- The Qualified Project Steward (QPS) training program
- other formal or informal corporate programs whose purpose is similar (developing individuals able to lead, coach, facilitate, train and provide consultancy support both internally and externally to clients, owners, constructors and designers who want to make a successful lean transformation of their enterprise or their projects.) e.g. Granya y Montero, JE Dunn, …

None of these studies are essential to making a start on the program but they will help to develop and refine it.

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TEACHING LEAN CONSTRUCTION FOR UNIVERSITY STUDENT(S)

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ABSTRACT

Lean construction has been considered as one of the key skills/attributes of construction management professionals. Lean educators have devised various teaching approaches and methods designed for different targeted audiences. This paper describes the Lean construction teaching approach for university graduate students. The description includes the course goal and objectives, content, and teaching-learning methods. One of the key features of the course that differentiate it from other literature in lean teaching is that it employs action learning in which the student learn how to solve a construction process problem and re-evaluate solutions they proposed. The authors of the paper consist of the instructor and previous students of the course; therefore both aspects of teaching and learning can be explored.

KEYWORDS

Lean construction, action learning, process, teaching-learning methods

INTRODUCTION

Reports on successful Lean Construction (LC) adoption emphasize that one of the important success factors is leadership and skill employed in implementation (Azevedo, Nunes and Neto, 2010; Keiser, 2012). Research also identified that educational barriers, including lack of technical skills and adequate training, as one of the great barriers to the sustainable implementation of LC (Bashir, et al., 2010; Sarhan and Fox, 2013).

When a company starts the journey of implementing LC on a construction project, several options are made available on how to mitigate the educational barriers. Common solutions are centered on relying on current employees with educational background in LC. If this option is not plausible, then the next option is to hire new personnel who have knowledge/experience or train the current employees on LC (Keiser, 2012; Hochstatter, 2013). Regardless of the available options, the industry has a legitimate expectation that graduates in architecture engineering and construction (AEC) fields will be well-versed in LC concepts and methods, as one of the latest advancements in project delivery (Johnson and Gunderson, 2009). LC has

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been recognized as one of the key attributes/skills for graduates in construction management (Ahmed, et al., 2014).

Reviewing the International Group for Lean Construction (IGLC) conference papers from 1993 to 2014 and Lean Construction Journal (LCJ) papers show limited publications on LC teaching in general, or university-based LC teaching in specific. From the existing literatures in LC teaching, educators have various approaches on how LC can be taught (Tsao, Alves and Mitropoulos, 2012). Hirota and Formoso (1998) found that in learning about LC, it is relatively straightforward for the students to understand and to apply some basic concepts like process, operation, conversion and flow activities and the general concept of waste; but it is not so easy for them to understand and comprehensively incorporate the LC principles and approaches. Therefore, exceptional learning process shared by academia and practitioners is one answer to face the challenges.

This paper describes the LC teaching approach at the School of Planning, Design and Construction (SPDC) at Michigan State University (MSU). The authors of the paper consist of the instructor and previous students of the course; so both aspects of teaching and learning can be explored. The description includes the course goal and objectives, content, and teaching-learning methods employed to demonstrate lean principles and application through different tools are elaborated. Course evaluation both from the instructor and previous students are also presented. While this paper's primary audience will be those who teach university students, it will also benefit the general diffusion of LC by sharing ideas on how to prepare future champions and practitioners of LC, as well as encourage other instructors to contribute their insights from years of teaching the subject matter.

COURSE DESCRIPTION

The course has been offered under the title "Lean Construction Principles and Methods." As the title suggests, the course solely addresses LC (Johnson and Gunderson, 2009). It is offered as a 3-credits elective graduate program course in Construction Management at the School of Planning, Design and Construction (SPDC). Since its introduction in the spring of 2002, the course has been offered every spring semester.

The course objective is to provide an understanding of LC principles and methods through reading, lectures, and discussion periods. Topics covered in the course include: Lean Production; Lean Construction principles and applications including lean design, lean assembly, lean supply, production control, lean work structuring, design of construction operations, and integrated project delivery. The course components have been evolving over the 13 years of being offered. Main reasons for this evolution are to incorporate feedbacks from the students and also to include the latest advancements in the LC community.

Most students taking the class are graduate students in Construction Management. However, there were small percentages from other majors, such as Civil Engineering, Urban Planning, Interior Design, Landscape Architecture, Business, Supply Chain, and Facility Management. Students are expected to have pre-requisite knowledge in some aspects of project management such as scheduling, estimating as well as in statistics and probabilities and also have proficiency with modern computer applications.

LEARNING OUTCOMES

The broad course outcome is focused on providing an understanding of LC principles and methods. By the end of the course, students are expected to have ability to:

1) Summarize the history and evolution of production paradigms
2) Explain and distinguish the principles of LC
3) Discuss and critique Relational Contracting methods such as Integrated Project Delivery and Integrated Lean Project Delivery
4) Use and compare lean-based productivity improvement techniques to study and improve construction operations through (a) Linear Scheduling, (b) Work Sampling and Value Stream Mapping in Construction, (c) Discrete-event computer modeling and simulation
5) Apply the Last Planner® System for production planning and control

COURSE CONTENTS AND TEACHING STRATEGIES

The course modules were designed to work together in increasing students' understanding as the semester progressed from lean theory to practical methods and applications of lean in the AEC industry. It begins with a general overview to characteristics of the construction industry focusing on the relationships among the participants and its influence on the effectiveness of construction project delivery. The instructor assigns the first chapter of Forbes and Ahmed (2011) as the required reading material to start the discussion and uses the Delta Design (Bucciarelli, 1999) simulation in the first class meeting.

This topic is followed by the concept of Lean Production principles and Lean Construction (LC) principles. It also covers characterization of project-based production systems and the AEC industry, and how these systems differ from other commonly found production systems (e.g., batch systems, linear production, and job shops), discussion of how production management systems evolved (from Taylor and Ford to Toyota) and how waste was perceived in different points in time. For this topical content, the next 3 chapters of Forbes and Ahmed (2011) are used as the background readings. At this stage also, students play the Light Simulation (a variant of the air plan game), LEAPCON Game (Sacks, Esquenazi and Goldin, 2007), Make a Card Game and Parade of Trades (Lean Construction Institute). Combined, the readings and simulations help students develop understanding of how the production system parameters are inter-related (e.g., batch size, cycle/lead time first pass yield, buffers) and how the production system in construction has evolved under LC concepts.

The course then moves forward on presenting how the LC concepts can be implemented in different areas of construction phases. Last Planner® System®, lean work structuring and construction crew designed introduced. The instructor used Chapter 5 and 6 of Forbes and Ahmed (2011) and Nerwal and Abdelhamid (2012) as reading materials. Depending on the available time, the DPR Game, the Villego Last Planner®System Simulation, or a simulated LPS® setting is conducted in the classroom. The instructor also presents case studies on lean work structuring and lean crew design. As transition to the next topic, which is integrated lean delivery (ILD), essentially the use of LC and a multi-party agreement contract, students play the "silent squares" simulation and read Schmaltz (2003) reflection on project management against the blind men and the elephant parable. The simulation helps students understand the concept of trust boundaries, collaboration and illustrates some of the issues associated with thinking of projects as collective enterprises. The instructor then presents a Lean/IPD project from the MSU campus. Some tools used in the project such as Choosing by Advantages (CBA) (Parrish and Tommelein, 2009)and Target Value Design (TVD) (Ballard, 2012) are also presented. During these classes, students also play some team work simulations such as the Marshmallow Challenge and Win as Much as You Can. A late addition has been Dr. Zofia Rybkowski adapted TVD simulation.

The last part of the course consists of two main topics; linear scheduling and discrete event computer simulation, and how it can be used to enable LC ideals. Discussion focused on how computer simulation can be used to understanding production problems, conduct production system design by analyzing and changing system level performance metrics as opposed to local utilization factors. EZSTROBE (Martínez, 1998) is studied in detail and used as the platform for simulation.

To help students build these abilities throughout the semester, the instructor uses different type of teaching strategies besides class lectures. Most of the strategies listed in Tsao, Alves and Mitropoulos (2012), especially reading assignments and facilitated discussion, simulations, case studies, and team projects (Tsao, Alves and Mitropoulos, 2012). The class takes place once a week for three hours and 50 minutes, and each class session combined the teaching strategies accordingly. The following sections describe the different teaching strategies that were employed in this course:

Readings and Reflections

To facilitate meaningful interaction and learning, the students were assigned weekly reading assignments and required to submit two questions per book chapter and/or paper from the readings. Specific instructions were assigned to the reading assignments. Students are suggested to read the readings twice; the first time, students should get a sense of the issues and note the writers approach to them, and in the second reading , students should highlight key ideas/claims the author makes, how each is supported, relevance of ideas to construction and finally implications and potential actions.. This task will facilitate students learning in critical thinking building and writing skills. Students are required to submit their reflections a day before the scheduled class meeting. This arrangement will give the instructor opportunity to assess their understanding and prepare materials that need to be focused/emphasized in the next day class.

Facilitated Class Discussion

Students' critical thoughts and questions based on the readings are discussed at the beginning of each class. The discussion gave students the opportunity to express their thoughts and ideas, listen to others, and learn collectively. It was expected that this activity will increase their understanding on the reading material. The instructor facilitates the discussion and provides insight and direction as necessary. In some cases, the instructor may find a pattern in the questions reflecting a misperception or a misunderstanding of a particular concept. This can be addressed in the class time by a focused discussion on the topic through a more instructor-led process. For example, it is frequently a theme that students will consider that Lean Construction is a 'spin-off' from Toyota's lean methods. The instructor may find it worthwhile to address this in the class and point out the shared pedigree and also the distinct unique aspects that separate LC from Lean Production.

*Table 1. Reading Assignments Used to Teach Specific Topic in LC**

Topic	Reading Assignments
Overview of Construction Industry	Chapter 1, 2 of Forbes and Ahmed (2011)
Lean production and LC principles	Chapter 3, 4 of Forbes and Ahmed (2011)
Lean Tools and Technique/LC application	Chapter 5, 6 of Forbes and Ahmed (2011)
Lean Integrated Project Delivery	Schmaltz (2003), Forbes and Ahmed (2011)
Computer Simulations/Operation Simulations	Paulson Jr (1994)
Linear Scheduling	Harris and Ioannou (1998)
On-site productivity data gathering and productivity improvement	Chapter 7 and 8 of Oglesby, Parker and Howell (1988)

*other paper assignments are given as appropriate

Simulations

Educational simulation has been discussed in the literature as one of tools in teaching LC (Hirota and Formoso, 1998; Izquierdo, Cerf and Gómez, 2011; Tsao, Alves and Mitropoulos, 2012). As discussed in the previous section, the course used many simulations to teach different aspects of LC. Table 2 shows the simulations and related LC concepts being taught.

Table 2. Simulation Exercises used to Teach Specific Lean Concepts

Lean Concept	Simulation Exercise / Teaching Tool
Design collaboration skills; Cross-functional teams; Product and Process Design; Set-based Design; TVD; Relational Contracting	Delta Design
Variation in Production	Parade of Trades; Dice Game
Impacts of batch size on project performance and Collaborations; Pull vs. traditional Push and Batch	LEAPCON Game; Light Fixture; Make a Card game
Last Planner® System	Villego; Last Planner® System Simulation
Pull Planning	DPR Pull Planning Simulation
Trust Boundaries and Collaboration	Silent Squares
Trust and Collaboration	Win as Much as You Can
Collaboration, Innovation, and Creativity	The Marshmallow Challenge, Ball Game, Task Switching
TVD	Adapted Marshmallow Challenge

Term Projects

The term project involves work sampling based on the work of Oglesby, Parker and Howell (1988). The project involves gathering data for on-site productivity and developing lean-based productivity improvement suggestions. Students observe construction operations to identify value added work from non-value added work, basically looking for examples of wastes (Muda) within an actual construction project operation. Students are divided into several groups. Each team consists of 3-4 students and will collect and analyse work data from a construction site, which they are responsible to find and get access to.

The term project is presented in A3 form. The form includes general information about the project such as name and location of project, general contractor, owner, architect, start and finish dates, scope of project including number of people employed by general contractor, number of subs, number of people employed by subs, dollar value of job, major problems and unusual aspects of job, safety information, union or non- union, etc. The A3 form then outlines findings and suggested improvements. Students are also required to discuss how easy it would be to implement the suggested improvements and discuss how the improvements relate to concepts of LC.

STUDENTS' EVALUATION ON THE COURSE

This section presents course evaluations based on the students' perception. The data was compiled from the Student Instructional Rating System (SIRS) (Michigan State University, 2011) which is independently administered and managed by Michigan State University and an anonymous survey managed by the first author of the paper. The SIRS collects feedback from students in all courses to provide faculty and teaching units with feedback on their instructional. SIRS forms are provided to students at the end of the semester either in paper format or as is currently through an online format. For each question in the survey, students are asked to evaluate the course based on categories of Superior (S), Above Average (AA), Average (A), Below Average (BA), or Inferior (I). The survey targeted graduates who took the course and presently are professionals who work within the AEC industry. Besides seeking information related to the course content and the teaching method, the survey also sought information about how the knowledge gained from the course is being used and how it contributed to their career. There are 93 respondents to the SIRS and 17 respondents to the survey.

General Evaluation

All respondents of the SIRS and the survey found the course interesting, enjoyable, and intellectually challenging at the same time.

As mentioned earlier, the course is an elective course. However, the respondents consider that it would be beneficial for all construction management students to have opportunity to take this course and it should be included as a compulsory course for master student in Construction Management major. Figure 1 shows the general student evaluation on different aspects of the course, including:

a) **Student interest**: constructed from evaluation of students' interest in learning the course material, the general attentiveness in class, and the intellectual challenging remark of the course.
b) **Instructor involvement**: constructed from evaluation of the instructors enthusiasm when presenting course material, interest in teaching, use of personal experience to help get points across in class and concern with whether the students learned the material.

c) **Student-Instructor interaction:** which is constructed from evaluation of the instructor's encouragement to students to express opinions, the instructor's receptiveness to new ideas and others' viewpoints, the student's opportunity to ask questions, the instructor's stimulation of class discussion.

d) **Course organization**: constructed from evaluation of the instructor's ability to relate the course concepts in a systematic manner, the ease of taking notes on the instructor's presentation, the course organization, the adequacy of the outlined direction of the course.

e) **Course demands**: constructed from evaluation of the appropriateness of the amount of material the instructor attempted to cover, the pace at which the instructor attempted to cover the material, the contribution of homework assignments to your understanding of the course materials relative to the amount of time required, the appropriateness of the difficulty of assigned reading topics.

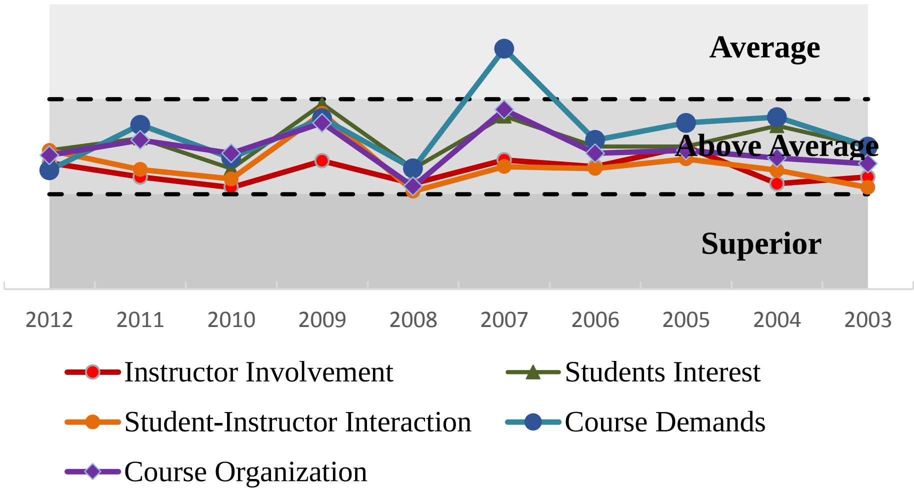

Figure 1. General Evaluation based on the SIRS

Course Contents

With the exception of some respondents who have been working the in construction industry, most of the respondents did not have prior knowledge of LC before attending the course. Therefore they value the course as an eye opener to a structured and systematic process of identifying and eliminating wastes in construction processes. The following is a quote from one of the responses:

"… The course improved my knowledge of understanding of not only LC but about the construction process in general. The course made me think deeply about how work is performed on construction projects and how it could be improved".

"The design of construction operations is something that is rarely mentioned elsewhere (in my experience) in civil engineering or construction management programs…"

Many respondents also valued the comprehensiveness of the course material especially related to balance between practical and theoretical content.

"I felt that I had a true 360 degree of the topic of (LC) after the course. The comprehensiveness of the course included discussing and analyzing LC's detractors."

However, some respondents found that the course is too intensive for a semester (Figure 1: course demands). The course content seems to be overwhelming for some students. Contradictory, some suggested adding material on financial benefits of implementing LC.

"I wish we spent more time on the effect of LC on project financials. This would include understanding how to quantify the benefits to those "non-believers". In my career I have learned that unless you can show the fiscal benefit of an effort, it seldom will get approved / acknowledged".

Teaching and Learning Methods

In general, respondents are satisfied with the teaching and learning approach. Table 3 shows highlights of "plus" and "delta" mentioned in by the respondents.

Table 3. Plus and Delta of Teaching and Learning Methods

+	Δ
- Very well organized curriculum/syllabus and well-developed course hand-outs - The course was well laid out with very clear expectations and requirements - Varied teaching and learning methods - Group project was helpful in understanding and applying concepts - Excellent simulation/activities to demonstrate concepts and reinforcing the principles. It also kept students' interest high during the class meeting - Readings do a good job for exposing students to topic, concepts and academic/industry discourse - Class Discussions help understanding the concept better and supported a very healthy exchange of ideas - The instructors valued the students as "learning partners", which enables learning. - Lots of examples that helped understand the principles	- Instead of a one-4 hour meeting, the class should be divided into two days in a week to allow the students to absorb the material before moving on - Essential tools such as 5S, fish bone, value stream mapping were touched on. A deeper study into some of these tools would be helpful. - Having more field trips and have more industry professionals talk about live cases to increase interaction with actual contractors, consultants and owners practicing the lean way on live projects. - Perhaps it would be better to offer this course in 2 consecutive semesters, given the subject breadth and coverage

Use of the Knowledge in the Professional Works

All of the graduates who responded to the survey have been using the knowledge they gained during the class in their professional works at different level of application.

"… It is one way we differentiate ourselves in the market".

Many comments also highlighted that listing LC class as one of courses they have taken, made them stand out in their professional career.

"Taking this course definitely provided me an edge & push in the professional world. Apart from applying lean principles and practices on my projects, it gave me skills and knowledge to be part of efforts facilitating and leading lean education & training outreach within my organization as well as other construction industry organizations".

CONCLUSIONS

The course content and teaching strategies have been evolving over the 13 years of teaching it. New content is added each year to include new development in the industry in general and in LC in particular. Improved teaching strategies have been used based on students' feedback and course evaluation.

The followings are some highlights of the course evaluation:

- Introduction to construction industry's characteristics and how it relates to productivity managements at the earlier class meeting plays an important role in providing background knowledge, especially for students outside of AEC industry.
- Variations in the teaching strategies are highly appreciated. There are two main reasons for this remark; 1) the class meeting was three hours and fifty minutes long, varied activities maintain student's attention makes the class alive and interesting, 2) Each topic in the course requires a particular teaching strategy, for example, the Parade of Trades simulation explains variation of production better that any lecture presentation can do.
- Readings and reflections assignment conducted before the class gives students the opportunity to learn before the class, help their critical thinking and at the same time give the instructor the opportunity to focus on the material that the students have challenges to understand.
- Presenting a case study in lean integrated project delivery provides a comprehensive example of LC implementation. Many students claimed that the presentation has provided them with knowledge on IPD better than reading several articles on different aspects of IPD.
- The term project give benefits in providing opportunity for students to have hands-on exposure to construction operations and to exercise critical thought about productivity improvement using systems thinking.
- Informal correspondences with some of CM program graduates confirmed that knowledge they learned during the LC class has significantly contributed to their career success.

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WASTE IN CONSTRUCTION

Nikolin, B., Herrera, J., McCready, T., Grau, D., and Parrish, K. 2015. "A Call for New Research in the Lean Construction Community: Alternative Work Schedules." In: *Proc. 23rd Ann. Conf. of the Int'l. Group for Lean Construction*. Perth, Australia, July 29-31, pp. 435-443, available at www.iglc.net

A CALL FOR NEW RESEARCH IN THE LEAN CONSTRUCTION COMMUNITY: ALTERNATIVE WORK SCHEDULES

Brent Nikolin[1], Jason Herrera[2], Tom McCready[3], David Grau[4], and Kristen Parrish[5]

ABSTRACT

While there is considerable research performed in the construction industry on the loss of productivity after a 5 day / 8 hour a day work week there is very little research exploring productivity with fewer work hours. Other industries have shown that they are more productive working shorter weekly schedules. Indeed, if we can produce a quality product with fewer resources, value stream is improved and a leaner process executed. More importantly, if we can be safer and improve quality of life we are achieving the most important tenant of lean, respect for people. To reinforce such notion, data shows that the US is 3% less productive than the other top 10 most productive countries in the world even though the US workforce works 21% more hours. Several countries, such as the Netherlands and Denmark, who work 29 and 33 hours per week, respectively, have a higher quality of life and have similar or higher productivity. This paper presents both a theoretical basis for alternative work schedules in construction as well as the results of a survey administered to trade contractor personnel, illustrating the potential safety benefits of a schedule change.

KEYWORDS

Productivity, quality of life, safety, alternative work schedules (AWS), waste.

INTRODUCTION

Field workers currently work 40 hours each week, spanning 5 days with 8-hour shifts per day. This study aims at challenging this practice and presents alternative work schedules that may improve safety, quality, productivity, and quality of life while reducing the carbon footprint. We borrow ideas from other industries, including healthcare, law enforcement, and others that have shorter workweeks (Geiger-Brown, Trinkoff and Rogers, 2011; Kelly, Moen and Tranby, 2011; Griffin and Moorhead 2012). These industries have shown that they are more productive and that their staffs

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prefer shorter schedules (Tippins and Stroh, 1993; Kim and Wiggins, 2011; Anthony 2012; Morrison and Thurnell, 2012; He, 2013). Moreover, data shows that the US is **not** one of the most productive countries in the world even though the US workforce works 21% more hours (Hall and Jones, 1998). This paper is a call for more research in the area of alternative work schedules in construction, as the authors believe that research in this area may compel owners to accept an alternative work schedule.

ALTERNATIVE WORK SCHEDULES

Combs (2010) implicitly defines alternative work schedules as any work schedule that is **not** 5-day, 9am–5pm (8 hour/day), 40-hour work weeks. Specifically, she defines *flextime*, where employees vary their start and end times while maintaining a required core hours. This schedule allows employees to select their own start and end times, but generally involves a 5-day workweek. A *compressed workweek* allows an employee to work 40 hours but in less than five eight-hour days within a week. Finally, *telecommuting* allows employees to work from home or another alternate location.

Alternative work schedules seem particularly popular in the public sector as well as in the healthcare industries (Tippins and Stroh, 1993; Combs, 2010; Geiger-Brown, Trinkoff and Rogers, 2011; Kelly, Moen and Tranby, 2011; Anthony, 2012; Griffin and Moorhead, 2012; Morrison and Thurnell, 2012; He, 2013). Most of these industries implement compressed workweeks that allow employees to work 40 hours each week in fewer than five days.

In 2002, 100 school districts in 6 states experimented with knocking off Friday. The school days were extended an hour or more to make up for the lost time. Schools found they could save money on transportation, heating and substitute teachers. Advantages were decreased absence by teachers and students, and the 5^{th} day was used for teacher training or personal appointments. There were also reports of improved student morale and behaviour (Donis-Keller and Silvernail, 2009).

Within the construction industry, in Netherlands and Denmark respectively, where standard workweeks are 29 hours and 33 hours, trade contractors work fewer hours and have a higher quality of life and are more productive, according to conversations we held with subject matter experts from those countries. Moreover, Morrison and Thurnell (2012) report that construction companies in New Zealand allow employees to use alternative work schedules to promote retention. While this study provides value, it focused on managers as opposed to field workers, who are the scope of this study.

CURRENT CONDITION IN THE USA: 40-HOUR WORKWEEK

Most industries in the USA work a 40 hour work week combined of (5) 8 hour work days (Combs, 2010). This has roots in the late 18th century, when companies started to focus on maximizing factory output. To do so, many companies sought 24/7 operation. At that time, the notion of increased efficiency was actually to make people work longer. In fact, 10-16 hour days were the norm (Combs, 2010). These incredibly long workdays were not sustainable and soon Robert Owen started a campaign to have people work no more than 8 hours per day. His slogan was **"Eight hours labour, eight hours recreation, eight hours rest"** (Widrich, 2014). Widrich (2014) further reports that Henry Ford was an early adopter of the 8-hour workday because it offered employees leisure time, which contributed to the market for the automobiles his factories were producing.

As in most US industries, construction companies typically employ a 5-day, 40-hour workweek. According to the authors' conversations with owners, they generally feel the 5-day, 40-hour workweek is the fastest and most cost effective way to build. Construction unions have also adopted the 5-day 40-hour workweek to be the standard for regular time wages.

SAFETY IMPACTS

The authors postulate the current workload has safety impacts on construction sites. Based on the 2014 Southern California (USA) safety logs from Turner Construction, the authors tracked the day and time incidents were reported. Fig. 1 illustrates the day of the week and the time of the day associated with incidents. Note that the average and median injury time for everyday of the week occurred between 9:50 am and 12:39 pm. This time corresponds to the timeframes of the morning and lunch breaks (Figure 1). These breaks in work pose the highest risk for safety incidents. By eliminating a day of work and more importantly breaks in work, there is a potential to drastically reduce the number of safety incidents that occur. This further compels the notion of implementing an alternative work schedule.

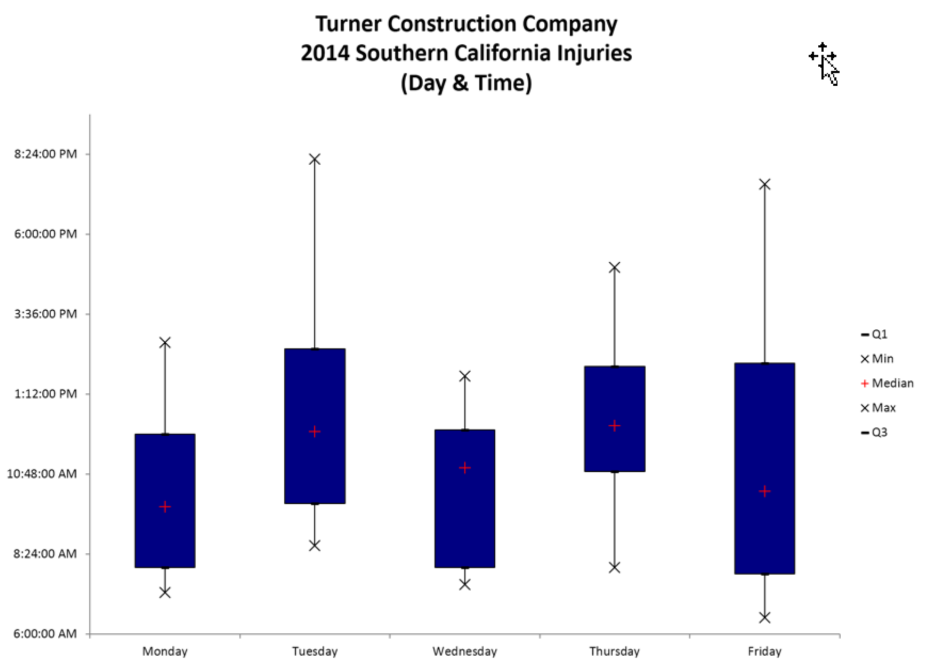


Figure 1: Box Chart of Injuries by Time and Day of Week.

SUSTAINABILITY IMPACTS

The 5-day, 40-hour workweek requires traveling to and from work 5 days each week, and this travel creates carbon emissions. According to the US Census Bureau, the average travel time to and from work is 50 minutes, totalling 250 minutes of driving per week, which translates to 15,600 minutes a year (McKenzie and Rapino, 2011). The average commute is 30 miles round trip, totalling 150 miles per week and 7,800 miles per year. According to American Forests (2015), each gallon of gas emits 17.68 pounds of CO_2. In 2011, the weighted average fuel economy of cars and light trucks combined was 21.4 miles per gallon (FHWA 2013). Thus, each person emits 6,453 lbs of CO_2 annually driving to and from work.

7,800 miles/year = 365 gal/year
365 gal/year x 17.68 lbs/gal = 6453 lbs/year CO2
21.4 miles/gal

NON-VALUE ADDED WORK IMPACTS

Each day a worker must get to his/her work area and prepare the day's task. This on average can be 20-30 minutes depending on how far and how much prep is required for the task. Additionally, there is a similar timeframe for cleaning up and vacating the work area. Finally, there is a morning and lunch break per day. Similar to the commencement and completion of the work day there is time associated with these breaks where workers must prep/close work area. This can be a combined 20-30 minutes of additional work.

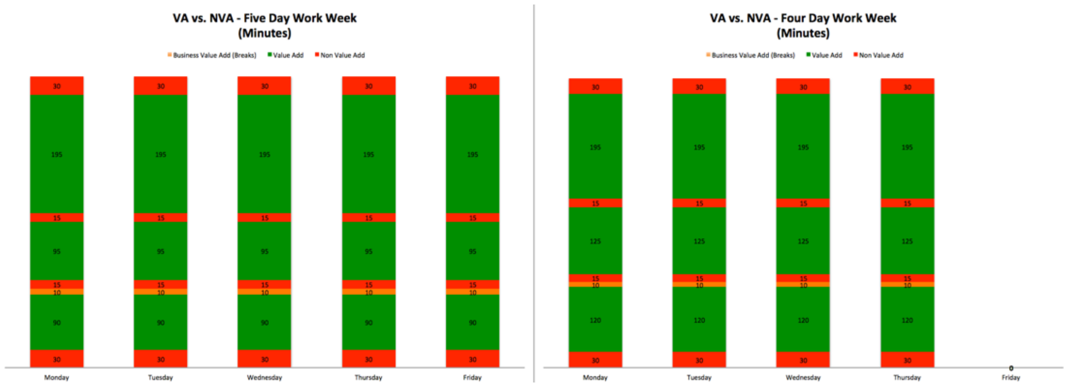
When looking at the effect of a 4 day/9 hour a day work week vs. a standard work week we can quickly quantify the effect. There can possibly be a 100 minute reduction in set-up time (Non-Value Added Work) just by downsizing to a 4 day work week. This means that a craftsmen needs to be about 7% more productive working a 4 day/9 hour a day work week to achieve the current state of productivity. If a plumber is currently installing cast iron pipe at the rate of 20 lf/hr, then in a 4 day/9 hour work week she needs to install 21.4 lf/hr. This is not a considerable change in productivity of the current craftsmen.

FLOW IMPACTS

The industry's ability to plan is often constrained by the on-going activities of the construction project. In a modified work schedule with 4 working days, the management/administrative side can continue to work the 5th day in order to plan work, transmit information (Submittals, RFI's, etc.) and increase flow. This day is an opportunity to plann for the coming work without the constraints and immediate demands of on-going construction activities. "Normally only about 50% of the tasks on weekly work plans are completed by the end of the plan week" (Ballard and Howell, 2003). With this in mind there is a compelling reason to put more emphasis on planning and achieving true flow so that when the craftspeople return to work they can be more productive.

INCREASED PRODUCTIVITY

There is not a wealth of data that shows there is an increase or decrease in productivity by working less than 40 hours a week. There is however, data that shows the decrease in productivity when working more than 40 hours. Figures 3 through 5 show various studies of the decrease in construction productivity when working longer than 40 hours. When looking at these results, however, the analysis is referenced at 40-hour work schedule. One could hypothesize that an increase in productivity could be observed if data was obtained for shorter work schedules, and hence extended to the left of the figures. There is a balance point where the number of work hours optimizes time, productivity and overall output. The question is what such balance point is.



Modified Work Week Example (4 days x 9 hours)												
		7:00 AM		9:30 AM			12:00 AM	12:30 PM			3:30 PM	
Day	Minutes Worked	Set Up	Work	Break	Set Up	Work	Lunch	Set Up	Work	Cleanup	Complete	
Monday	540	30	120	10	15	125		15	195	30	--	540
Tuesday	540	30	120	10	15	125		15	195	30	--	540
Wednesday	540	30	120	10	15	125		15	195	30	--	540
Thursday	540	30	120	10	15	125		15	195	30	--	540
Friday	--	--	--	--	--	--	--	--	--	--	--	0
		120	480	40	60	500	0	60	780	120	0	

Set-up/Clean-up Time 400
Working Time (WIP) 1760

Standard Work Week Example (5 days x 8 hours)												
		7:00 AM		9:30 AM			12:00 AM	12:30 PM			3:30 PM	
Monday	480	30	90	10	15	95		15	195	30	--	480
Tuesday	480	30	90	10	15	95		15	195	30	--	480
Wednesday	480	30	90	10	15	95		15	195	30	--	480
Thursday	480	30	90	10	15	95		15	195	30	--	480
Friday	480	30	90	10	15	95		15	195	30	--	480
		150	450	50	75	475	0	75	975	150	0	

Set-up/Clean-up Time 500
Working Time (WIP) 1900

Ratio of workweeks WIP (4x9)/(5x8) 93%

Figure 2: Non-value Added vs. Value Added Activities of Craftsmen

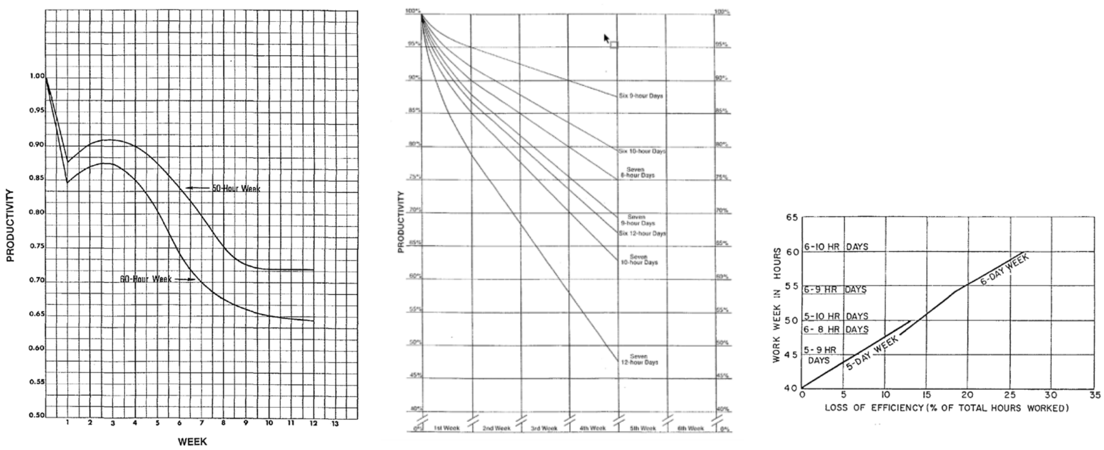


Figure 3: Cumulative Effects of Overtime on Productivity (BRT 1974)	*Figure 4: Productivity as a Function of Successive Weeks of Overtime (NECA 1969)*	*Figure 5: Overtime Inefficiency (O'Connor 1968)*

QUALITY OF LIFE

Based on responses to an interview questionnaire, we also postulate that the quality of life for the craftsmen can improved in a smaller workload. Based on 112 craftsmen responses from the sheetmetal, carpentry and electrical fields, the highest ranked modified workweek was the 4x10 (Figure 3). All the workers believed that working 4 days a week would be the most optimal for safety, productivity, and quality of life. One consideration is that the survey did not factor in compensation for the various work weeks presented. We postulate that this may have lead to the craftsmen not to considerate modified workweeks less than 40 hours since they would lead to a reduced compensation.

From a quality of life perspective	Best	Better	Good	Would Not	% of Best votes
Normal Hours 7:00 to 3:30	8	27	53	4	7.48%
Modified Shift 3-12 Hour Shifts	1	3	19	68	0.93%
Modified Shift 4-10 Hour Shifts	85	7	1	0	**79.44%**
Modified Shift 4-9 Hour Shifts	13	41	26	21	12.15%

From a productivity perspective	Best	Better	Good	Would Not	% of Best votes
Normal Hours 7:00 to 3:30	12	24	53	1	11.21%
Modified Shift 3-12 Hour Shifts	0	4	17	67	0.00%
Modified Shift 4-10 Hour Shifts	68	14	8	16	**63.55%**
Modified Shift 4-9 Hour Shifts	10	29	15	8	9.35%

From a safety perspective	Best	Better	Good	Would Not	% of Best votes
Normal Hours 7:00 to 3:30	16	21	50	3	14.95%
Modified Shift 3-12 Hour Shifts	0	0	18	69	0.00%
Modified Shift 4-10 Hour Shifts	66	20	5	0	**61.68%**
Modified Shift 4-9 Hour Shifts	11	52	20	8	10.28%

Figure 6: Survey of Trades on Working Hour Preference

CURRENT CONDITION WORLDWIDE: ALTERNATIVE WORK WEEK

Worldwide, 40-hour workweeks are relatively uncommon. Figure 7 illustrates workweek lengths across the world. Based on anecdotal evidence, these shorter workweeks seem to make workers more productive, as we tend to better utilize their time when they feel constrained in terms of work time availability. Complementary, employees must focus on what is important, and often encourage the attainment of the expected quality of the finished work. The United States ranks forth in terms of hours worked/gross domestic product. However, this statistic is misleading, as the United States hours worked per worker are greater than other top ten countries by more than 20% and the top 20 but more than 10% (OECD, 2015).

Figure 7: Average Workweek Lengths across the World (PGI 2015)

A CALL FOR NEW RESEARCH

Based on the authors' experience to date, owners refuse to adopt or implement an alternative work schedule based on an adverse. However, other industries have successfully adopted alternative workweeks in the United States. Moreover, construction organizations in other countries have also adopted shorter workweeks resulting in the benefits discussed above. We would like to invite the IGLC community to critically assess the productivity, safety, quality of life, and sustainability impacts of alternative workweeks for the labor force. Specifically, the authors make the following suggestions for further research inquiries:

- Conduct simulations to support or refute the notion that alternative workweeks improve productivity, safety, and quality of life while reducing carbon emissions.
- Address the question of productivity comparisons across nations represented at IGLC to understand how and why various workweeks impact productivity and quality of life.
- Conduct a "5 Whys" analysis to understand how and why alternative workweeks were implemented in other industries (e.g., in the healthcare sector) and determine whether or not these same indicators of success exist in the construction industry.

CONCLUSION

Many industries have successfully adopted alternative work schedules to the benefit of their employees and organizations. This study serves as a call to action for future research to analyse the benefits and barriers of adopting alternative work schedules for the construction labor force. The statistical analysis of work field data implies that job incidents are related to work breaks, while most workers prefer a shorter weekly work span with the same amount of work hours (i.e. 10 hours a week, 4 days a week). Based on this data and also on evidence from previous studies, it can be stated that a modified work schedule is likely to result in safer jobsites with more satisfied employees, while securing a reduction in carbon emissions.

ACKNOWLEDGMENTS

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A CASE STUDY ON CAUSES AND CONSEQUENCES OF TRANSPORTATION WASTE

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ABSTRACT

Transportation is a waste category that has not been much explored in the literature on construction management. Moreover, the existing studies about it have focused mostly on its impacts and not on the causes. This paper aims to present the results of a second implementation of a method in order to identify, measure and characterize the transportation waste on physical flows of construction processes. A case study was performed in a residential building project, which involved the use of the Light Steel Frame technology. The research methods comprised the following sources of evidence: direct observation on site (work sampling and time studies), participant observation in planning meetings, and analysis of existing production control data. A database was produced containing a description of each transportation event, including pictures, causes, consequences, and its relationship with other types of waste, such as making-do, unfinished work, work-in-progress and rework. The main contributions of this study are concerned with the understanding of the nature of this type of waste, highlighting the classification of transportation waste causes, its main consequences and the relationships between this kind of waste and other ones.

KEYWORDS

Waste, transportation waste, making-do, physical flow.

INTRODUCTION

Waste is any human activity, which absorbs resource, but creates no value, such as mistakes, which require rectification, waste of time, production of items no one wants, inventories (Womack and Jones, 2003. Since 2011, a group of researchers from the International Group of Lean Construction (IGLC) has been involved in a project called "Understanding Waste in Construction" aiming to conceptualize waste in construction theory (Understanding Waste in Construction, 2015) with the publication of important contributions towards the development of such theory (Viana, Formoso

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and Kalsaas, 2012; Koskela, Sacks and Rooke, 2012; Koskela, Bølviken and Rooke, 2013; Bølviken, Rooke and Koskela, 2014; Perez, Costa and Gonçalves, 2014).

Viana, Formoso and Kalsaas (2012) put forth that many studies about waste in construction have mostly focused on the consequences and not on the causes, showing that further studies are necessary to increase the existing knowledge. In addition, transportation is a waste category that has not been examined much in those studies and in the literature on construction management.

In the present study, it was understood as the real problem the large amount of transportation waste found in construction processes. This statement was perceived by three exploratory studies and by the literature review (Thomas, Sanvido and Sander, 1989; Alarcón, 1994). These exploratory studies indicated that 36% to 46% of the activities of the mortar coating process were related to transportation activities.

Therefore this paper aims to identify different causes and consequences of transportation waste, associating them with other waste categories such as making-do, unfinished work, work-in-progress and rework. These four additional waste categories are included in the study due to their relevance at jobsites (Fireman, Formoso and Isatto, 2013). In order to achieve this objective, a case study in a Light Steel Frame (LSF) building project was carried out. This paper presents the results of the second implementation of a proposed method that aims to identify, measure and characterize transportation waste on physical flows of construction processes, made up of tools, indicators and definition of concepts to measure such waste from the viewpoint of their incidences, causes, consequences and the association with other categories of waste.

TRANSPORTATION WASTE AND OTHER CONSTRUCTION WASTE CATEGORIES

Transportation waste is described by Ohno (1997) as materials handling activities that generate cost and do not add value. Formoso, et al. (1997) state that waste is due to inefficiencies, which occur during the use of equipment, material, labor and capital in values superior to that required for the production. For these authors, transportation waste concerns excessive or inappropriate use of materials and components due to poor planning or inefficient jobsite logistics. Bølviken, Rooke and Koskela (2014) corroborate with Formoso, et al. (1997), defining transportation waste as waste that happens in the flow perspective, related to unnecessary movement of people or unnecessary transportation of materials.

The authors of this paper seek to contextualize transportation waste in construction, understanding that despite the fact that transport is a non-value adding activity, and efforts for its reduction and elimination are possible, transport activities are unlikely to be eliminated from the construction process. Therefore, due to the understanding that certain types of transport activities are necessary to guarantee the efficiency during the complete process, this paper considers that transportation wastes are due to the unnecessary transportation of materials, i.e. consuming resources such as time, which creates additional cost, but does not add value to the product.

Other kinds of waste have recently been examined in construction and they could potentially be associated as causes or consequences of transportation waste, such as making-do, unfinished work, rework and work in progress. Those waste categories and transportation waste unleash similar consequences, such as reduction of the working safety conditions, waste of material and increase in the share of non-value adding activities. Table 1 presents the current definition of these categories of waste and their main references.

Table 1: Possible associated wastes categories to transportation waste

Waste category	Definition	References
Making-do	It refers to a situation where a task is started without all its standard inputs, or the execution of a task is continued although the availability of at least one standard input has ceased.	Koskela (2004)
Rework	Doing something at least one extra time due to non-conformance to requirements.	Love, Mandal and Li (1999)
Work in progress	Working on fairly small tasks left from the previous plan	Hopp and Spearman (1996)
Unfinished work	It includes rework and small finishing tasks that are left over after a crew leaves a workstation.	Fireman, Formoso and Isatto (2013)

RESEARCH METHOD

Design Science Research was the research approach adopted in this investigation. This is a form of scientific knowledge production that involves the development of innovative constructions, intended to solve problems confronted in the real world, and simultaneously makes a prescriptive scientific contribution (Lukka, 2003). An important outcome is an artifact that solves a domain problem (March and Smith, 1995).

This investigation is part of a broader research project, which aims to propose an artifact represented by a method to identify, measure and characterize the transportation waste on physical flows. This paper presents the second stage of this research, in which the method proposed is implemented. The artifact was developed along the first case study in Project A, which was carried out on a traditional construction process, the mortar coating process with mechanical application, in a residential building project, located in the city of Salvador, Northeast of Brazil.

The second case study which is presented in this paper involved the implementation of the method in a residential housing project in Canoas, in the south of Brazil, called Project B. This project was chosen due to the use of LSF technology, a relatively new building system in Brazil, allowing the comparison of the causes of transportation waste in two different technologies, a traditional and an industrialized one. Project B consisted of 178 LSF houses built on shallow type raft foundation. The case study took place from November to December 2014, over a period of six weeks. Four processes were monitored: structure assembly; Oriented Strand Board (OSB) installation; roof execution; and facade execution. Twenty-five site visits of 4-6 hours each were conducted by the research team. Three types of data were collected during the site visits: (i) mapping physical flows; (ii) work sampling; and (iii) monitoring of transportation waste events. Additional data was collected from 6 weekly work meetings, such as Percentage of Plan Complete and causes of non-completion of the work packages. Some additional qualitative data were obtained through informal interviews and meetings with field project personnel, such as workers, crew leaders, field engineers and project manager. A seminar was carried out at the end of the study with the field team, in order to present and discuss the results.

DESCRIPTION OF THE PROPOSED METHOD

STAGE 1: MAPPING PHYSICAL FLOWS

The first stage of the method consists of mapping physical flows by using a process diagram and a layout diagram to document the processes (Ishiwata and Katō, 1991). The process diagram represents the sequence of various activities that make up a process. The layout diagram shows the places where each task is performed and indicates the main flows of materials and operations (Ishiwata and Katō, 1991).

STAGE 2: WORK SAMPLING

Work sampling was used to measure the amount of productive, contributory and non-contributory work. Productive tasks are the value-adding ones. Contributory works are the ones that support value-adding tasks, such as transportation. Non-contributory or unproductive tasks do not contribute at all for project execution (Picard, 2002). As the focus of this investigation is on transportation waste, the worksheet adopted involved a detailed breakdown of transportation activities. In this study it was adopted a 94% confidence level and 6% relative error, it was taken 1873 observations.

Throughout the modeling of flows, some transport activities have been identified that could be deemed necessary, avoidable and unnecessary. Thus, in order to identify those activities and measure the waste of time, the definitions of Santos, Formoso and Hinks (1996) were taken as a basis and adapted to the transportation activities, as delineated below:

a) **Necessary Transport Activity**: this refers to a transport activity that needed to occur for the flow of the process. Those were identified as the contributory tasks.
b) **Avoidable Transport Activity**: this refers to an inefficient transport process that causes waste of time, caused sometimes by lack of process control and can be easily reduced. This occurs due to planning flaws, inadequate sizing labor teams, supplies or equipment failures, omissions or design errors, rework, etc, and as a consequence those activities generate obstruction in the flow. Those were identified in the contributory tasks.
c) **Unnecessary or Idle Transport Activity**: this refers to unnecessary transport activity that caused waste of time, which was not planned and should be eliminated or complete inactivity of the workers on some transport activity, which may be intentional or the result of a physical state of predisposition. Those were identified as non-contributory work.

STAGE 3: OBSERVING TRANSPORTATION WASTES EVENTS

In order to characterize the transportation wastes, three constructs were defined based on data obtained on the previous steps, as follows:

a) **Transportation Waste Event:** this is defined as an unexpected phenomenon that happens in a transport activity, referring to an observable and registered fact in a particular place and at a particular time that affects the physical flows, causing a waste of time, the execution of unplanned tasks, and producing inefficiencies to the process.

b) **Cause:** this is defined as the origin of a certain transport waste event in a certain situation.

c) **Consequence**: this is defined as the effect or the result of a certain transport waste event or fact found.

The transport waste events identified were registered on a worksheet, including the following information: (i) photo; (ii) date; (iii) number of record; (iv) number of the same event per day; (v) people involved in the transport; (vi) type of transport; (vii) recurrent case; (viii) waste description; (ix) cause; and (x) main consequences.

Table 2 shows the classification of the main causes identified based on the nature of each waste, and Table 3 shows the classification with the main consequences of transport wastes identified throughout the study in Project B. It was considered that each transportation waste event could be related to one cause and to more than one consequence, but not exceeding three.

Table 2: Causes of transportation wastes' classification

Cause	Definition
Access/ Mobility	It refers to any kind of route obstruction, which makes the transport activity difficult.
Storage	It refers to inappropriate space for material storage or material stored in an inappropriate manner.
Equipment	It refers to unavailable, damaged or inappropriate equipment for transportation, generating the adaptation of other equipment for this transportation or appropriate equipment, but used in an inappropriate manner.
Team	It refers to insufficient number of workers to perform the transportation activity.
Packing material	It refers to the poor packing condition of the material, which makes the transportation slow and difficult.
Information	It refers to the lack of necessary information for the employees for correct transportation performance.

Table 3: Categorization of transportation wastes' consequences

Main consequences	Definition
Damage of material	The material being transported is damaged during the transportation activity.
Unsafe work conditions	Unsafe work conditions were caused due to the transportation activity.
A new transport operation	Anew transport operation would be required in the near future
A longer distance	A worker must move greater distance than it was planned.
Ergonomic problem	The ergonomic conditions of transportation operations are inadequate.

STAGE 4: ASSOCIATION BETWEEN TRANSPORTATION WASTE WITH OTHER WASTE CATEGORIES

Direct observation was performed in order to associate the transportation waste events with the work-packages from which they came from. Work-packages include both formal (planned) and informal work-packages. These were classified according to their nature (unfinished work or new package), as suggested by Fireman, Formoso and Isatto (2013). The metrics used for measuring the incidence of informal work-packages were the percentage of informal work-packages in relation to the total number of work-packages. These work-packages were categorized in: (i) completed formal work-packages; (ii) incomplete formal work-packages; and (iii) informal work-packages. Therefore, the percentage of transportation waste events in each group could be measured taking the number of events observed as part of completed formal work-packages, incomplete formal work-packages or informal work-packages. If the transportation waste events could not be related to any work package that was associated with an inventory or a logistic operation depending on the activity they supported.

In addition, each transportation waste event was related to another type of waste occurring at the same time, such as making-do, unfinished work, rework and work in progress. All the transportation waste events were analyzed to check if another kind of waste was involved or not.

RESULTS

PROCESS CHARACTERIZATION AND PHYSICAL FLOWS

The materials to be used in the following days were stored near by the proper raft. Horizontal transport was performed with a telescopic handler and with a tractor. The vertical transport was performed by hand through the facade scaffoldings. A facade scaffolding was used for the execution of the facades.

The findings of the process diagram and layout diagram of the four processes studied showed a similar relationship between the activities. Considering all process activities, 10% represent processing activities, 40% represent transport activities, 20% represent stock activities and 30% inspection activities.

DISTRIBUTION OF WORKERS TIME AND TRANSPORT ACTIVITIES

Table 4 shows the work sampling results. Concerning the productive work, frame assembly presents the highest productive time (66% observations), followed by the roof installation (37%), frame assembly (24%) and OSB installation (23%).

Table 4: Work Samplings Results

Time		Frame Assem.	OSB Inst.	Roof Inst.	Facade Execut.	Global LSF
Productive Work		24%	23%	37%	66%	33%
Contributory work	Necessary Transport	12%	12%	7%	3%	11%
	Avoidable Transport	17%	4%	4%	1%	6%
	Others	23%	25%	11%	13%	22%
Non-contributory work	Unnecessary Transport	0%	14%	0%	0%	5%
	Others	24%	22%	41%	17%	23%
Total time		100%	100%	100%	100%	100%

Analyzing all the times destined for transportation activities, the random observations revealed that the OSB installation process was one where more time was allocated to carry out transport activities (30% of observations), followed by frame assembly (29%), and the roof installation (11%) and the façade execution (4%). It was considered, in this study, that avoidable transport and unnecessary transport are a time waste factor, thus 17% of the time destined by frame assembly is a waste of time, 18% for OSB installation, 4% for roof installation and 1% for façade execution.

TRANSPORTATION WASTE EVENTS

This study identified 23 transportation waste events. Table 5 presents the transportation waste events identified, organized by their causes. Besides the five main consequences identified in this case study, the waste of time was continuously identified as an impact arising from the transportation wastes events. In terms of qualitative data, the results show that access and storage were the main causes of transportation waste events, 35% and 39% respectively of the transportation wastes events, and the creation of a new transport operation (32% of the events). In addition, the unsafe work conditions (32% of the events) were the main consequences of the transportation waste events.

Table 5: Transportation wastes events

Cause	Transportation waste events	Transport activity with waste event	N. of events	Consequences
Access/Mobility	Presence of obstacles (materials, rubble, infrastructure hole) in the access routes.	Horizontal transport of the structure by hand	6	A new transport operation Unsafe work conditions Damage of material
		Vertical transportation of the structure by hand	1	Ergonomic problem A longer distance
	Door smaller than the workbench	Workbench transportation for OSB installation	1	Damage of material
Storage	The loader driver must come down to remove other manually stocks	Loader transport to storage area	5	Damage of material
		Transport loader to the raft foundation	2	Unsafe work conditions
	Employee improvises stock	Unloading of OSB to the storage area	2	A new transport operation
Equipment	Lack of a loader	Transportation structure by hand on the ground	2	Unsafe work conditions Ergonomic problem
	Telescopic handler with difficulty	Loader transport to storage area	3	Damage of material
Team	Lack of one of the collaborators on the scaffolding	Vertical transportation of the structure	1	Unsafe work conditions

ASSOCIATION OF TRANSPORTATION WASTES EVENTS WITH OTHER WASTE CATEGORIES

The transportation wastes events were classified according to the work-package (formal or informal) or stock and logistic activity that they supported (Figure 1). The results show that 39% of the transportation waste events were not related to work-packages, due to the fact that those flow activities such as logistics and inventory are not included in the weekly work plan as an assignment. In addition, 13% of the events were observed during the performance of informal work packages, and 48% of the events happened during the performance of a formal work package.

The 23 transportation waste events collected were reanalysed in order to identify other categories of wastes, which these events could be associated with (Figure 2). In some events other waste categories studied were identified as cause, in other cases they were identified as consequence, and also in some other cases, it was possible to observe that other waste categories studied could be both cause and consequences. It means that the relationship with other waste is not always uni-directional, being often cyclical. The findings show that 39% of the transportation waste events are related to making-do waste. Although, it seems that a large percentage (35%) of the transportation waste events identified happens for other reasons, different from the existence of other waste categories.

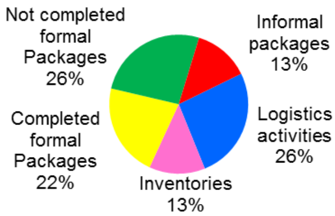

Figure 1: Association of the transportation wastes events with work packages

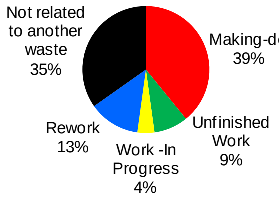

Figure 2: Wastes categories identified at transportation wastes events

The integrated use of the four tools, such as process diagram, layout diagram, work sampling and photographic records with the data collected from weekly work meetings, allowed the calculation of eight main indicators, as shown in Table 6.

Table 6: Tools, indicators and results

Tool	Indicators collected	Results obtained
Process Diagram	(1) Percentage of transport activities in relation to all process activities	40%
Work sampling	(2) Percentage of productive time	33%
	(3) Percentage of time related to transportation activities (necessary, avoidable, unnecessary)	23%
	(4) Percentage of time waste related to avoidable and unnecessary activities	11%
Worksheet with photographic records	(5) Main causes of transportation wastes	Access Storage
	(6) Main consequences of transportation wastes	Unsafe work conditions A longer distance
Worksheet and Layout Diagram	(7) Place with most occurrences of transportation waste events	Access routes
Worksheet and data collected from weekly work meetings	(8) Other main waste category identified during the identification of transportation waste events	Making-do waste

According to data collected from the seminar, it was observed that project managers and field engineers were aware of their logistic problems; however, they were surprised concerning the high percentage of time spent in transportation activities, the large amount of transportation wastes events identified, and their causes and consequences. For the project team, their major logistic problem was concerned with equipment; nevertheless the results pointed out that the greatest amount of transportation waste came from storage causes and access/mobility, because despite the project had equipment, it was difficult to used them because the route access were not adequate.

CONCLUSIONS

The first contribution of this paper is the better understanding of the meaning, identification, measuring and characterization of transportation waste in construction. The transportation waste event was defined as an unexpected phenomenon that happens in a transport activity, referring to an observable event with the possibility to register the fact, in a particular place and at a particular time, that affects the physical flows, causing the execution of unplanned tasks, and producing inefficiencies to the process. Thus, a transportation waste event can be characterized by its occurrence, its cause and its consequences.

The cause of a transportation waste event was defined as the origin of a certain phenomenon in a certain situation and a long this study, the main causes of transportation waste identified were related to the access/mobility, storage, equipment, team, packing material and information. From the perspective of the consequences of a transportation waste event, it results from facts found, such as damage of material, unsafe working conditions, a new transport, a longer distance, and ergonomic problems.

Therefore, the study identified and measured that all transportation activities are not waste, given that certain types of transport activities are necessary to make the flow possible. In order to discriminate the different types of transportation, a classification of the transportation types was proposed in this study. Necessary transport is defined as a transportation activity that needed to occur to contribute to process flow; avoidable transport, means a transportation activities which can be reduced; and the unnecessary transport refers to a transportation activity which was not planned and should be eliminated. Thus, the transportation activities that can be reduced (avoidable transport) or eliminated (unnecessary transport) were understood as a waste of time.

The practical contribution of the implementation of this method refers to the combined use of the tools and indicators to identify, measure and characterize the transportation waste from the viewpoint of its recurrence, causes and consequences. The use of the method increases the information for managing the transport waste in construction, providing a wide range of qualitative and quantitative data.

In addition, it was possible to validate that the classification of the causes identified and proposed based on a traditional process case would be tailored to an industrialized process. Most of the transportation events identified in LSF system studied originated from access/mobility and storage problems. The next stage is the assessment of its utility as an artefact and practical contribution.

Another important conclusion is the strong relationship between transportation waste and making-do, due to the fact of that both could be a main cause and main consequence of the waste events identified. It means, that this relationship is not always unidirectional, being sometimes cyclical, therefore it is difficult to distinguish which kind of waste comes first.

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A CONCEPTUAL FRAMEWORK FOR THE PRESCRIPTIVE CAUSAL ANALYSIS OF CONSTRUCTION WASTE

Formoso, C.[1], Bølviken, T.[2], Rooke, J.[3] and Koskela, L.[4]

ABSTRACT

An initial step towards a prescriptive theory (a set of concepts) to inform the elimination of waste on construction projects. The ultimate intention is to identify the most important types and causes of waste in construction and outline the principal causal relations between them. This is not a straightforward process: the relationships form a complex network of chains and cycles of waste.

Waste is defined as the use of more resources than needed, or an unwanted output from production.

A conceptual schema of Previous Production Stage > Production Waste > Effect Waste is proposed and applied to the causal analysis of two major types of waste: material waste and making do.

KEYWORDS

Waste, value, value stream, causality, networks of waste

INTRODUCTION

The aim is a theoretical contribution to a practical ambition: increased productivity in construction through a reduction in waste. Waste can be defined as the use of more resources than needed, or an unwanted output from production (Bølviken, Rooke and Koskela, 2014). In fact, the strategy to increase productivity through the decrease of waste is probably one of the common features of all so called "lean" approaches.

The paper is based on previous historical, theoretical and empirical work on waste presented at previous IGLCs: Viana, Formoso and Kalsaas (2012) review existing construction management literature, finding a lack of conceptual development; Koskela, Sacks and Rooke (2012) provide a historic overview of the term, demonstrating its strong normative dimension; Koskela, Bølviken and Rooke (2013) argue that Ohno's (1988) original list of wastes is not universal, but related specifically to manufacturing; Bølviken, Rooke and Koskela (2014) propose a taxonomy of construction wastes within a TFV framework (Koskela, 2000).

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The objective is a more thorough conceptualization, that can be used for systematic waste reduction; specifically, an initial understanding of the causal relations between different kinds of waste. The difficulty lies in the complexity of these relations; not only the sheer number of possible relations, but also the qualitatively different logistical, financial and social dimensions on which they lie (Andersen et al., 2008). For this first step, we have focussed on two types of waste (making do and material waste) and have restricted our analysis to the logistical dimension (primarily the 'physics' of production).

We first recap and update the Viana, Formoso and Kalsaas (2012) review. This is followed by a conceptual exploration of the nature of cause in production. Finally, drawing on previously published case studies, we present models of the causal networks surrounding the two types of waste.

REVIEW OF PREVIOUS STUDIES

This section presents a review of papers that have investigated waste in construction, including concepts adopted, metrics, and type of feedback provided, mostly based on a previously published literature review (Viana, Formoso & Kalsaas 2012). It is complemented by additional papers published between 2012 and 2015 (Fernández-Solis and Rybkowski, Z. 2012; Sarhan, Pasquire and King 2014; Perez and Costa, 2014, Bølviken, Rooke and Koskela 2014). The main sources were IGLC conference papers, Lean Construction Journal and seven mainstream construction management journals[5]. After the first selection of papers, a database was created in a citation manager, in order to check duplicates and apply quality criteria in the selection of papers. Some additional references cited in the selected papers were also included in the database. After several refinements, 56 papers were selected. These were analysed in detail, considering the following content: (i) the concept of waste adopted, whether it was explicit or not; (ii) the kind of waste that has been analysed; and (iii) the main contribution of the paper to the topic of construction waste. The main conclusions of the literature review follow:

(a) Many papers do not present a clear definition of waste, either explicit or implicit. Only 41% properly presented a conceptualisation of waste in a broad sense, and 16% defined only a specific kind of waste that was addressed, such as rework, making-do, or defects. Three different groups of concepts were identified in the set of papers: (i) waste as non value-adding activities (29 papers); (ii) waste as material loss (10 paper); (iii) specific types of waste (17 papers), such as rework;

(b) There are different conceptualizations of the same type of waste, which makes it difficult to perform a meta-analysis of the data. For instance, several papers discuss the incidence of rework in construction projects (e.g. Ashford, 1992; Love 2002). However, none of them contain much discussion of the concept of rework, nor a clear definition from the industrial engineering point of view. Moreover, the source of data is not always fully described, there is little contribution on how to measure rework, or investigation of its root causes.

[5] Architectural Engineering and Design Management; Building Research & Information; Construction Management and Economics; Engineering, Construction and Architectural Management; Journal of Architectural Engineering; Journal of Construction Engineering and Management; Journal of Management in Engineering

(c) Two main types of contribution can be identified: investigation of causes; and production of metrics. However, nearly half of the papers were mainly based on surveys. A wide range of indicators has been used, ranging from physical quantities, such as the volume of debris taken from the site (Gavilan and Bernold 1994; Poon et al., 2004), to costs, such as defective products (Ledbetter, 1994) and rework (Hwang et al., 2009). Time has often been used, especially to identify the share of non-value adding activities (Horman and Kenley 2005; Forsberg and Saukkoriipi 2007; Yu et al. 2009; Kalsaas 2010), as well as the number of non-value adding steps (Lapinski, Horman and Riley 2006; Mao and Zhang, 2008).

(d) Proposed actions for reducing or eliminating waste are also very diverse. Some papers describe attempts to change practices by implementing lean techniques (Nahmens and Ikuma, 2011), while others use simulation models to support decision making, by testing measures to reduce the share of non value-adding activities (e.g. Tommelein, Riley and Howell 1999; Sacks, Esquenazi and Goldin 2007).

(e) The number of papers on the development of methods for identifying and measuring waste is relatively small and most focus on two types of method: the measurement of material loss, including direct and indirect waste (e.g. Sloyles 1976; Formoso et al., 2002) and value stream mapping for assessing the share of non value-adding activities and designing a future state (e.g. Choi et al., 2002; Yu et al 2009).

Overall, the number of papers is small, considering its relevance for the field of construction management. Some studies from the Lean Construction community pointed out the need to use a broader conceptualization of waste, based on the idea that it is necessary to remove activities that do not add value from the perspective of the client (Formoso et al., 2002; Koskenvesa, 2008; Koskela, 2004). Most studies do not discuss the conceptualization of waste at an abstract level. Some simply adopt an operational definition in order to guide data collection.

STATIC, DYNAMIC AND COMPLEX WASTE

Waste in construction can be divided into static and dynamic. Static waste is additive, whereas dynamic waste propagates in complex and emergent ways. The relationships between wastes can take several forms, including linear chains, cycles, and networks. The relationships between wastes can be either uni-directional or interactive.

STATIC WASTE

Static waste can be divided into two types: point-wise, occurring in the framework of an individual tasks, adding to the use of resources, but always in the same way; system-wide, consisting of sub-optimal work-flows, e.g. unnecessary tasks.

The salient feature of static waste is that it does not increase unpredictability (variability). It has been designed into a task or production system, i.e. is a question of bad design. Thus, the solution is to redesign the task or production system.

DYNAMIC PROPAGATION OF WASTE

This section is based on Hopp and Spearman (1996, 2000).

There are two types of variability in flows of production: process-time variability and flow variability. Process-time is the time required to process a task at one workstation. It is subject to: natural variability (minor fluctuation due to differences in operators, machines and material); random outages; setups; operator availability;

and rework (due to unacceptable quality). Waste is a major cause of this variability. Flow determines the arrival of jobs at a particular workstation. Where this deviates from an agreed schedule, waste is also a major, though perhaps not the only cause.

It can be shown that variability increases lead time. If it is not possible to reduce variability, one or more of the following have to be accepted: long lead times and high WIP levels, wasted capacity, lost output.

Queuing theory is useful in demonstrating how waste generates other waste in the temporal dimension of production. Another important result contribution is to show that variability early in the line is more disruptive than variability late in the line.

Countermeasures against dynamic waste include continuous improvement and optimal production control (e.g. pull/push decisions, location and sizing of buffers).

CHAINS, CYCLES, NETWORKS AND PATTERNS OF WASTE

Both Ohno (1988:55) and Shingo (2005:154) introduce a conceptualization of causal relationships between the different wastes where one type of waste (overproduction) is a 'primary' waste generating other wastes. Koskela, Bølviken and Rooke (2013) refer to this phenomena as a chain of wastes with one waste acting as a core or lead waste. The reasoning of all three is that by attacking this core, one can also eliminate the wastes caused by it. There can however be good reasons to focus on the resulting waste. For example, if overproduction is the effect of one or more chains of waste, an operational strategy focusing on the reduction of this effect can trigger a root cause analysis leading to the core wastes in the system. In this example, overproduction can be seen as both core and result waste; instead of a linear chain, we see a cycle of waste generating waste (Ohno, 1988, p. 55).

Furthermore, if one waste in a cycle is causing several others and these result wastes are also interconnected, we can conceive a complex network of wastes. The network is characterized by the causal interconnections between its nodes.

Finally, the causal connections between nodes as not necessarily uni-directional. They can be reciprocal, A leading to B while at the same time B leads to A.

Our line of reasoning has taken us from the conceptualization of a linear chain with clear causes and effects to a complex network with both uni-directional and interactive connections between the nodes. In such a complex network we may not be able to identify and analyse all the connections. We see a pattern, but are not able to decompose or decode the network in all its components and interconnections.

CONCEPTUAL MODEL

Here, a conceptual model is proposed for representing causal relationships between different types of waste. The model is concerned with production control, pointing out categories of waste that should be the focus of waste elimination in production management. If the focus is another stage of construction projects, such as design, procurement, supply chain management, other waste categories should be identified.

The conceptual model is represented as a network of constructs, as shown in Figure 1, being divided into three main zones:

1. Effects (terminal or result waste): these are formed by traditional categories of waste that are strongly related to the effects of wasteful production processes. Some of these categories have been the focus of several measurement studies, such as material losses, and non value-adding time.

2. Production waste: these are the categories that are relevant for production control. Some of them represent concepts that are not widely known or used as a focus for improvement in the industry, such as making-do, work in progress, unfinished work. In fact, its inclusion is due not only to its importance in performance improvement, and also because these concepts might be useful to show non-obvious problems. Waste is not always obvious: it “often appears in the guise of useful work” (Shingo 1988:71). Each production waste category has cause-effect relationships not only with terminal waste categories, but also with other production waste categories.
3. Previous production stages: in this zone some of the previous production stages are represented, since failures in those stages are the root causes for the production waste categories. Understanding the relationships between previous production stages and production categories is important for devising strategies for waste elimination.

This model is relatively consistent with other conceptualisations. Fernandez-Solis and Rybkowski (2012) proposed three different waste concepts: discrete; synergistic; and systemic. The first corresponds to terminal waste; the second includes production waste, plus categories related to some of the previous production stages at the project level; the third mostly relates to the loose coupling of stakeholder organizations, resulting in duplication of effort and miscommunication. The concept of institutional waste (Sarhan, Pasquire and King 2014), though based on a different theoretical framework, is similar to synergistic waste, existing at the supply chain level.

Figure 2 presents constructs and connections identified in a case study by Formoso et al. (2002), Figure 3 presents a similar network for a study of making do (Formoso et al., 2011).

CONCLUSION

The causal models provided in the previous section represent a first step towards a systematic and comprehensive analysis., providing a three part conceptual framework and outlining some causal relationships between major categories of waste. They represent waste as a complex and dynamic causal network in which waste generating further waste, sometimes in a uni-directional, but often in an interactive and/or cyclical manner. Figures 2 and 3 demonstrate the application of the generic model to empirical studies of actual waste generated on site.

The models are limited to a logistical analysis, but are capable of being extended to include financial and organizational dimensions. The conceptual model does not, as yet, include a measurement of magnitude which would show the increase in downstream waste generated by upstream waste. Perhaps for this reason, it does not yet indicate any candidates for a core waste or wastes. Alternatively, it may be that such central wastes are not to be identified in construction and that the causal mechanisms are much more diffuse than in manufacturing.

The next step will be to build on these models, supplementing them with further conceptual development and additional empirical data.

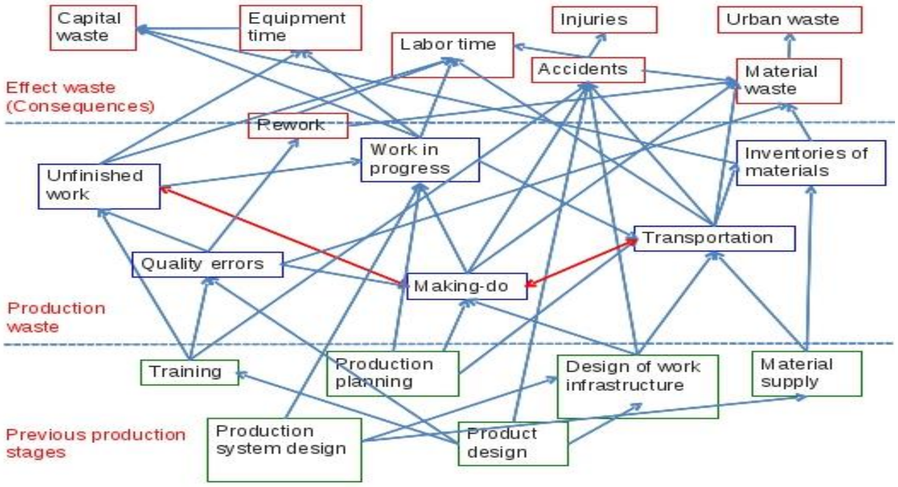

Figure 1: Taxonomy of waste – preliminary proposal

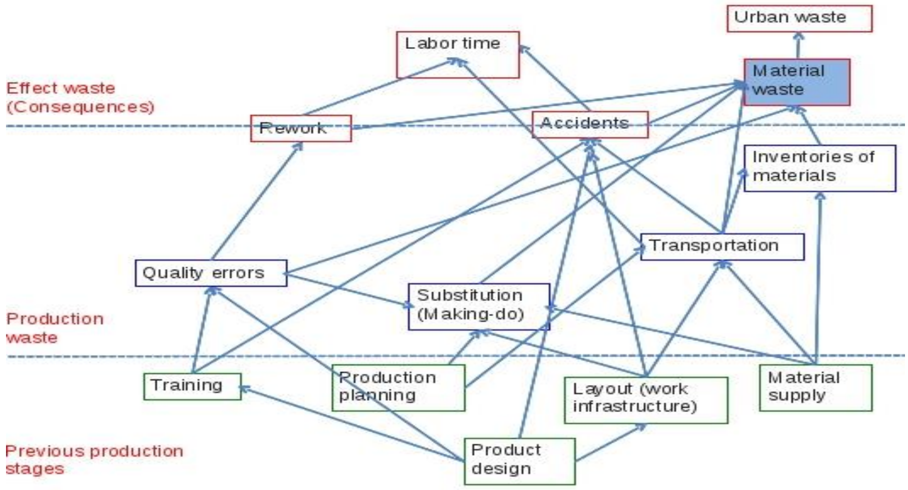

Figure 2: Causal network for material waste (based on Formosa 2002)

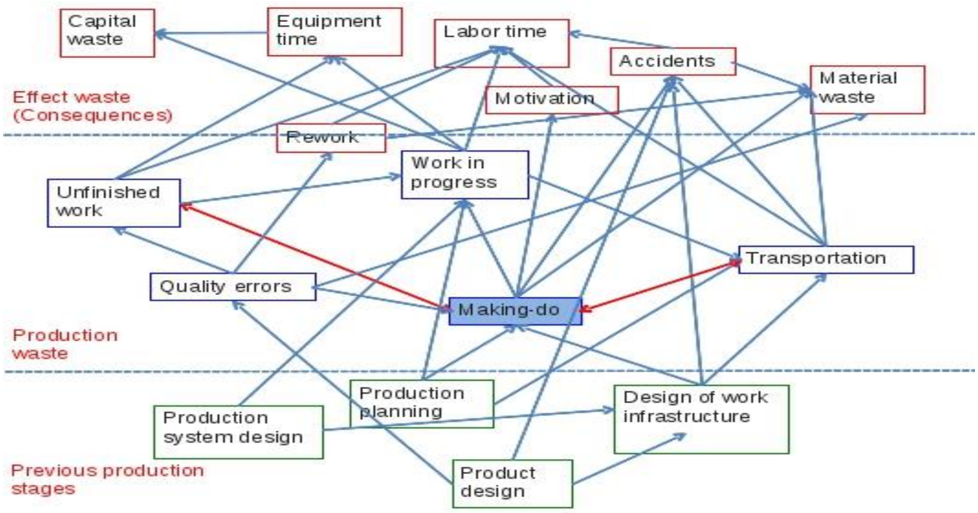

Fig 3: Causal network for making do waste (based on Formoso, Sommer, Koskela and Isatto 2011)

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WASTE IN DESIGN AND ENGINEERING

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ABSTRACT

The purpose of this paper is to shed light on the feasibility of using waste drivers to explain waste in a design and engineering setting. Waste drivers are defined as the mechanisms that have the capacity to create waste, under certain conditions. The waste can occur in design and engineering, and as a consequence of design and engineering. Waste include, e.g. reduced build ability and usability, with increased costs, time, and quality. The distinctiveness of the engineering process has been central when attempting to identify the waste drivers. The complexity associated with waste in design and engineering may indicate that the conventional manufacturing wastes do not suffice in the context of identifying waste in design and engineering. Based on researched literature and a case study, a list of waste drivers was identified. This paper should contribute to the understanding of design and engineering processes. Thus, potentially making design and engineering processes more predictable.

KEYWORDS

Waste, mechanisms, engineering, design, management.

INTRODUCTION

Design and engineering (DE) processes play an important part throughout the product life-cycle. Typically, the design phase accounts for a small portion of the total product cost, however, it can impact the life-cycle costs significantly (Verma and Dhayagude, 2009). The increased market competition as a result of globalization and the higher level of complexity in projects calls for more efficient and predictable DE processes. Consequently, it becomes important to ensure that time is spent on value-adding activities, providing value to the customer within budget and in a timely manner. In order to achieve this, it is necessary to identify the mechanisms that lead to waste in DE.

Several studies have been conducted in an effort to conceptualize waste in DE. An extensive amount of literature and research has been written on the topic of waste in manufacturing and construction. However, it appears to be limited focus on the mechanisms that lead to waste in DE. It seems like previous literature and research has been stuck in a loop trying to relate the wastes of DE to the seven conventional

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manufacturing wastes described by Womack and Jones (2003). More often than not, researchers end up adding their own categories in an effort to cover the waste drivers of DE. To some extent, previous research fails to consider distinctive elements of DE, such as creative processes, motivation, and social relations. Furthermore, DE is a learning process (Kalsaas, 2011), which adds an additional layer of complexity when trying to define, identify, and eliminate waste. These elements need to be addressed in the aforementioned context. Based on this background the following research question was explored:

What are the mechanisms that might lead to waste in design and engineering?

The scope of this study is limited to the conceptualization of waste in design and engineering, with an emphasis on the mechanisms that has the potential to lead to waste. This includes waste which is realized in the design and engineering processes and waste these mechanisms might generate in processes further down-stream.

The selected approach was constructive research design, which is a procedure for developing constructions that can contribute to theory in the field of research (Lukka, 2003). This included gathering data from multiple sources, such as literature and a case study. The majority of the source material consisted of literature on topics such as lean, engineering, design, management, and learning. The findings from literature were supplemented with the collected data from a case study. The case company studied is a subcontractor for the oil and gas industry. The findings were used to present a generic representation of the waste mechanisms in DE, thus, they are meant to be applicable to DE in different industries and organizations.

During the process of investigating the characteristics of DE, several topics and theories were considered relevant to the research question. The emphasis on the elimination of waste is a central element in lean (Womack and Jones, 2003), which led to investigating the concepts of lean, including lean manufacturing and lean construction, and the Toyota Production System (TPS). A lot of research on waste in DE has been conducted by LAI at MIT. These studies were used as a starting point for this study. Several hundreds of papers, articles and books were read, especially papers from the International Conference on Engineering Design (ICED) and the International Group of Lean Construction (IGLC) were investigated.

This paper covers some basics about the nature of DE, and then there is an overview of some previous ideas of waste. The possibility of using previous ideas of waste in a DE setting is explored. Lastly, a suggestion for a possible conceptualization of waste in DE is presented.

THE NATURE OF DESIGN AND ENGINEERING WORK

Human beings are central actors in DE. Thus, one can argue that it is important to consider additional aspects, when compared to manufacturing or conventional production processes. From the researched literature, several authors suggested that information is the product of DE processes, such as Bauch (2004). Bauch (2004, p. 1) states that “Product development […] can be understood as some kind of information creation factory”. Due to the relevance of information in DE, the aim of analyzing and improving the processes in DE can be considered an analysis of the generation of different information types, as well as their respective qualities (Vosgien, et al., 2011). This differs from manufacturing, where the products are physical objects. Simon (1996, p. 138) goes as far as to suggest that "The proper study of mankind is the science of design, not only as the professional component of a technical education but as a core discipline for every liberally educated man." Even though one does not need to agree with this statement, it is plausible the knowledge of technical systems and analysis does not suffice in order to understand what leads to successful and efficient design. The design process is a complex cognitive endeavor, and it is critical to understand these cognitive processes in order to improve existing design methodologies (Pahl, 1997; Dym, et al., 2005). Creativity and innovation are important in order to generate good solutions, this is often accomplished through experimentation (Ulrich and Eppinger, 1995). In this context, creativity can be seen as the process of coming up with novel ideas that have value. Innovation can be seen as the process of realizing these ideas. Without creativity in design it is impossible to have innovation, and it is mandatory to have innovation in order to improve quality, create new markets, and extend the range of existing products (Verma, Das and Erandre, 2011).

The process of engineering design typically consists of the following five steps: formulation, synthesis, analysis, evaluation, and documentation (Verma, Das and Erandre, 2011). Creativity is especially important in the first two steps of the process, since new thinking or rearrangement of existing data is required (Verma, Das and Erandre, 2011). The process typically begins with the analysis of the product’s intended usage and context. The analysis leads to a heterogeneous set of loosely related details, and possibly some insight to potential solutions. The design problem is initially structured and its solution defined through its implicit properties. The solution is further elaborated in relation to additional requirements, and if the context and requirements determines a distinctive solution, it may be derived algorithmically. Then designing is basically just the problem’s transformation from its intentional to its extensional form (Takala, 1993). However, it is common that the algorithmic rules are unknown, or that the problem lacks specifications. This typically leads to an explorative approach of trial and error, which is usually not a random effort. The paradigmatic solution is compared against an increasingly maturing set of requirements, and modified as needed. In this aspect, design is described as the convergent evolution of solutions (Yoshikawa, 1981; Takala, 1993). Its progressive evolution may branch, and lead to detours and backtracking, which eventually will result in a path to the solution (Takala, 1993). Simon (1996) suggests that detours are a natural part of the design process. Even though a general notion of the goal is known, barriers that are encountered along the way call for a continuous adaptation in accordance to these obstacles. Ballard (1999) argues that design requirements and their respective solutions evolve as the process progresses. This is what Thompson (1967) depicts as reciprocal dependencies: relationships where output from one activity establish the next (Kalsaas and Sacks, 2011).

The design phase comes to a halt when the engineers run out of time (Reinertsen, 1997). This might indicate that the ideal solution cannot be achieved, and that decisions must be made in accordance to what is perceived as good enough (Bølviken, Gullbrekken and Nyseth, 2010). Typically, this is the solution that is most consistent with the original requirements.

Male, Bower and Aritua (2007) point out three challenges that are distinctive to design:

- Requirements are often subject to interpretation, since they tend to be vaguely formulated
- Problems become increasingly clearer as solutions evolve over time
- The design process is an interactive, multidimensional effort that represents the interests of several stakeholders

Kalsaas (2013a) suggests that these challenges are caused by the need for design to mature. Kalsaas (2011) conceives design as a learning process, where one develops and optimizes a solution. Thus, the aspect of learning can be seen as particularly relevant in the context of DE. Illeris (2007) divides learning into three dimensions: the cognitive dimension, the psychodynamic dimension, and the environment. The process of acquiring knowledge takes place in the intersection of the cognitive and psychodynamic dimensions, which subsequently interacts with the environment. According to Illeris (2007), there are different variants of learning in the cognitive dimension: assimilative, accommodative, and transformative. The general form of learning, which is termed assimilative, is the kind of learning that evolve progressively through encounters with new impressions and impulses, in everyday life. In DE, this learning can be in the form of acquiring additional knowledge and competence in how to use CAD software efficiently. Accommodative learning is described as the process of relating what is already known into situations that one cannot understand, e.g. applying knowledge to a different context than where it was originally used. Such learning requires creative efforts and is very important when attempting to improve existing work practices, e.g. continuous improvement (kaizen). Accommodative learning in DE can be the knowledge of dealing with uncertainties and how to apply it to different projects, even though the objectives and specifications may differ. Transformative learning is described as developing new mental models, and can be related to a state of crisis on the personal level.

The presented theories, as well as several others, have been central when exploring the mechanisms that lead to waste in DE.

WASTE IN DESIGN AND ENGINEERING

According to Morgan and Liker (2006), eliminating waste is the heart of TPS. Activities can be divided into value adding, non-value adding, but necessary, and non-value adding. True lean thinking does not focus on one-dimensional elimination of waste. It is necessary to understand that it is required to eliminate all the three types of interrelated waste, known as the three Ms, in order to achieve waste elimination (muda, muri, mura).

Ōno (1988, p. 54), who is considered the father of TPS, explains that *"waste refers to all elements of production that only increase cost without adding value"*. Macomber and Howell (2004) state that waste is commonly understood as anything that is not value. They elucidate that waste is the expenditure of effort or resources that do not generate value. Similarly, Koskela (1992) explains that waste is activities that takes time, resources or space, while not adding value. Several of the authors refer to waste as something that consumes resources without adding value, thus the resources that can be wasted in DE should be identified. The seven conventional waste categories describe waste through, e.g. rework, waiting, and overprocessing (Morgan and Liker, 2006). However, these categories do not explicitly describe what is actually wasted. Sugimori, et al. (1977, p.554) state that TPS works on the assumption that “anything other than the minimum amount of equipment, materials, parts, and workers (working time) which are absolutely essential to production are merely surplus that only raises the cost”. Thus, the unnecessary use of resources can describe what is wasted. Bauch (2004) identifies and describes the factors that are wasted in DE. He divides the waste into primary and secondary waste types, where the underlying causes are the waste drivers. The primary waste types affect the flexibility, and impacts: quality, time, and cost to market. This include, e.g., the constructability and usability of the product. Instead of using what Bauch (2004) refers to as secondary waste types, the authors of this paper rename it to resources. Resources include man-hours, time, money, et cetera. Thus, waste of resources can, e.g. be spending more time on a given product, compared to what is achievable with a more effective and predictable DE process.

In addition to the resources that can be waste in DE, it is important to emphasize that DE processes can generate waste in processes down-stream as well. Thus, it can differ between what is wasted in DE, and what is wasted due to DE. The wastes that occur due to DE will be context dependent. For example, the downstream process can be a construction process, which arguably can have different waste than a manufacturing process. However, the waste in downstream processes is likely to impact the time, cost and quality to market of the product, in a similar fashion to the waste generated by the DE process.

Based on the provided definitions of waste, and the suggestions to what is wasted in DE, a proposed definition can be made. Waste in DE might be defined as resources spent on activities that negatively impact the cost, time or quality to market of the designed element. The market includes both internal and external customers.

CATEGORIZING WASTE IN DESIGN AND ENGINEERING

According to Vosgien, et al. (2011), defining waste is essential to increase process efficiency. Slack (1998) concluded that the primary manufacturing wastes could be applied to DE. However, due to the complexity associated with DE, the set of categories was not considered all inclusive. Furthermore, several other publications (Slack, 1998; Womack and Jones, 2003; Bauch, 2004; Morgan and Liker, 2006; Oehmen and Rebentisch, 2010) have addressed this issue, and it typically involves transposing the seven manufacturing wastes to the area of DE, often supplementing with additional categories, such as Koskela’s (2004) making-do (Vosgien, et al., 2011). Macomber and Howell (2004) discuss the force-fitting of the seven manufacturing wastes, and based on observation they introduce what they call the two great wastes: not listening and not speaking.

It is also worth pointing out that several of the manufacturing waste categories will be a natural part of the engineering process, and it may depend entirely on the situation if these activities should be defined as waste or not. As an example, if information is stored deliberately to enable reuse in later assemblies, then it might be considered value adding (Oehmen and Rebentisch, 2010). In manufacturing, overproduction is considered the most important waste, this cannot be defended regarding projects that are one-of-a-kind, like a design project often is (Koskela, Bølviken and Rooke, 2013).

SELECTING A DIFFERENT APPROACH

Bauch (2004) tries a different approach. Bauch (2004) uses the seven manufacturing waste categories. He also builds on these by adding three additional categories[4]. Bauch (2004) refers to the categories as drivers, since they describe why waste is happening, and not what waste is or what is wasted. In addition, he divides the categories into sub-drivers. The authors of this paper found this interesting, and wanted to explore these ideas further.

Bauch's (2004) idea of sub-drivers might have the potential to create a less ambiguous representation of waste in DE, and will perhaps even make waste easier to identify. Based on the sub-drivers created by Bauch (2004), and other literature, such as Oehmen and Rebentisch (2010) and Oppenheim (2011), a list of waste drivers was created. This was supplemented with findings from the case study and personal experience. The usefulness of creating a list of waste drivers is considered to be supported by Koskela, Bølviken and Rooke (2013), who tries to conceptualize waste in construction processes. They explain that the seven wastes stem from a manufacturing context. Hence, it does not cover the design aspect. They explore the potential of creating a list of waste drivers in construction. Koskela, Bølviken and Rooke (2013, p.3) explain the benefit and purpose of such a list: "Such a list would be instrumental in creating awareness on the major waste types occurring in construction, as well as mobilizing action towards stemming, reducing and eliminating them.". DE is part of the construction process, and as a consequence, the statement by Koskela, Bølviken and Rooke (2013) should be relevant in this context as well. The purpose of waste drivers in DE could be to create awareness about the mechanisms that potentially contribute to waste. Managers and employees could benefit from such a list. Knowing what contributes to waste could enable people to eliminate it. Terms like rework and overproduction are too ambiguous in a DE setting to provide a sufficient image of waste in this context. The waste drivers are an attempt to provide a better image of waste in DE.

A table was created in order to evaluate if the waste drivers should be sorted into the conventional seven waste categories. The purpose was to categorize the drives in accordance to the seven manufacturing wastes. However, the process of categorizing the drivers was time consuming and challenging. The relationships are complex, context specific and, thus, very much open to interpretation. It became apparent that many of the waste drivers could be tied to multiple of the conventional categories. Thus, sorting waste in this manner was perceived to not serve any significant purpose. This was much due to the aforementioned issues. It should be noted that the waste drivers could be related to each other. Still, they should be more distinguishable in the context of DE, compared to the conventional seven categories. Furthermore, the waste drivers are more specific, which makes it easier to identify measures that can mitigate or eliminate waste.

Based on Bauch (2004) and Kalsaas (2013b) waste drivers is defined as a mechanism that has capacity to create waste and to be hindrances of workflow, under certain conditions. The definition of waste drivers used in this paper is similar to Bauch's (2004) definition of sub-drivers. Furthermore, the seven manufacturing

[4] Limited IT-resources, Lack of System Discipline and Re-invention

waste categories are not defined as drivers like Bauch (2004) does. This is since the authors of this paper do not perceive the manufacturing wastes as drivers in the context of DE. For example, rework is a value-adding activity, and not a mechanism that generate waste. Rather, rework is a result of such mechanisms.

The three aforementioned authors (Bauch, 2004; Oehmen and Rebentisch, 2010; Oppenheim, 2011) are perceived to use different resolutions when describing the waste drivers. Thus, it was tried to determine a fitting resolution, in order to adapt the previous concepts. The main objective was to make the waste drivers identifiable and manageable, in the context of eliminating or reducing waste in organizations. In order to accomplish this, a fitting resolution had to be chosen.

It was tried to find somewhat a golden path between high and low resolutions. While many of the drivers are connected, one of the main criteria when creating the list was to avoid overlapping, to the extent possible. However, this was not completely achieved, since the waste drivers are highly context dependent. Also, no drivers should be effects; the drivers should be the mechanisms that might lead to waste. This interface is a bit ambiguous, as several drivers can be effects of others, depending on the context. Even though many of the drivers can be effects, all of them are mechanisms that lead to waste. In relation to DE, the authors argue this is an improvement compared to using the manufacturing waste categories. An expansion of the list might include sub-drivers of each driver, and categorizing the drivers in a sensible manner. An overview of the suggested waste drivers is provided in table 1.

*Table **1**: Overview of Suggested Waste Drivers*

Waste Driver	Description
Ineffective Verifications	Include ineffective testing, prototyping, approvals, and transactions Example: tests that are more costly than the risk they are trying to mitigate, or information is dispatched without sufficient testing
Poor Coordination	Poor planning, scheduling, prioritizations, unsynchronized processes Example: Tasks completed in a sequential order, when they should be performed concurrently
Task Switching	Interruptions that forces a person to reorient themselves Example: unnecessary hand-offs
Capacity Constraints and Overburdening	Interruptions of workflow as due to unavailable resources or exceeding the capacity of an entity Example: tasks are hampered due to unavailable staff, tools, and equipment
Lack of Required Competence	Not possessing the skill or knowledge required to conduct the task in question Example: ineffective use of IT tools, such as BIM, due to limited skill
Unclear, Goals, Objectives, and Visions	Misaligned goals, objectives, and visions in relation to, e.g., customer requirements Example: employees pulling in different directions, reducing the efficiency
Information Overload	Large batch sizes, and distributing and storing information that is not needed Example: excessive information can make the relevant information harder to access
Unclear Authority and Responsibility	Unclear expectations in relation to performance and organizational roles Example: overlapping competencies and responsibilities
Insufficient Means of Communication	Means of Communication that are insufficient to handle the reciprocal interdependencies of the DE processes, or means that demand excessive time and effort, without adding additional value Example: not utilizing the Big Room (BIM rooms) when it would be beneficial
Interpretability of Information	Information represented in an ambiguous manner, resulting in misinterpretations Example: Lack of standardization of documentation
Accessibility of Information	Information cannot be accessed when needed Example: missing input, leading to, e.g. making-do
Underutilization of Resources	Allocating resources in a less effective way than possible Example: inappropriate use of competence

Over-engineering	Adding features that do not add value for the customer Example: increased development and production costs as a result of exceeding requirements
Unnecessary Data Conversions	Avoidable data conversions occurring due to, e.g., use of inappropriate tools or a lack of standardization Example: re-formatting and re-entering data
Lack of Knowledge Sharing	Not exchanging information, expertise, or skills among entities Example: New projects starting below the potential starting point by not reusing previous solutions
Processing Defective Information	Processing information that is based on a valid need for information, but the need is not sufficiently fulfilled Example: defective information processed is not discovered and affects other processes
Changing Targets	While change is considered to be part of the iterative DE process, internal or external changes of requirements, that is not sufficiently compensated, can create waste Example: changes can lead to rework, especially when the changes occur late in the process
Cooperation Barriers	Includes transactional barriers, opportunistic behavior, risk aversion, et cetera Example: lack of ownership negatively affecting motivation, which could be mitigated by the use of Integrated Project Delivery (IPD)

CONCLUSION

Previous attempts at conceptualizing waste have typically involved transposing waste in DE into the seven manufacturing categories. However, it was concluded that this approach was not feasible, since it, to some extent, fails to account for the waste in DE. In addition, this approach does not provide enough information for employees and managers to actually do something about waste. This is because the approach does not explain why waste is happening. In contrast, the waste drivers presented are, in essence, explanations to why waste happen. Thus, it is possible to implement measures to mitigate or eliminate waste by using the waste drivers. Waste drivers are defined as mechanisms that have capacity to create waste and to be hindrances of workflow, under certain conditions. The waste can occur both in the DE processes, and as a consequence, where the waste is, e.g. reduced constructability and usability, or expenditure of resources such as, time and money.

The waste drivers were evaluated on usability, completeness, practical relevance, and generality. Generality and practical relevance might be considered high. However, the usability is hard to determine, since the waste drivers are not yet tested. The completeness is also debatable, since there are several theories and literature that might be considered relevant when conceptualizing waste in DE. Obviously, it was impossible to investigate all the possible aspects, but the waste drivers might provide an improvement compared to previous attempts at conceptualization. Based on the findings, the waste drivers presented in this paper is argued to be a theoretical contribution to the understanding of DE processes. Further analysis of the usability, and a purposeful categorization of the waste drivers, is suggested for future research.

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THEORY

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NINE TENETS ON THE NATURE OF VALUE

Frode Drevland[1] and Jardar Lohne[2]

ABSTRACT

The Lean Construction (LC) community commonly agrees upon that the goal of projects is to deliver value. However, value as a concept is an ambiguous one. Not surprisingly, a commonly agreed upon definition of value has not yet been found. We find the lack of such as definition to be problematic, as it makes any high-level discussion of value challenging.

Reviewing the LC literature, limited effort in regards to tackling the fundamental nature and base definition of value is found. This paper aims to provide this through presenting nine tenets on the nature of value. It starts out by providing an overview of selected definitions found to be pertinent to value in the context of construction projects, notably from within economics, marketing and those that are employed within the LC community. Thereafter, nine tenets pertinent to the concept of value and the reasoning behind them are presented. Finally, we discuss several value related concept, such as waste, in relation to the presented tenets.

KEYWORDS

Lean Construction, Value, Theory

INTRODUCTION

The Lean Construction (LC) community commonly agrees upon that the goal of projects is to deliver value (Emmitt, Sander and Christoffersen, 2005). However, value as a concept is an ambiguous one (Salvatierra-Garrido, Pasquire and Miron, 2012). Not surprisingly, a commonly agreed definition of value has not yet been found (Thyssen et al., 2010). According to the authors' experience from previous IGLC conferences, the lack of such a definition leads to everyone having their own mental models of what value is. Consequently, higher level discussions on the subject of value are difficult. It is for example a challenge to discuss how to maximize value if it is not first agreed upon what value is.

Reviewing the LC literature, limited effort in regards to tackling the fundamental nature and base definition of value is found. The most thorough approach to the subject – Salvatierra-Garrido et al. (2010) – identify five main features of value in the literature. Notably, no comprehensive definition of value is presented. Equally, little effort is made to clear up problematic areas such as the subjective-objective

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dichotomy. Furthermore, their value features are not bolstered by in-depth discussion, and are mainly substantiated by citing literature. Accordingly, the literature review leading up to this paper revealed that some of the overall "truths" about value that are being purported seem to have the entered the LC literature by authors quoting non-academic sources. Emmitt et al. (2005) is perhaps the most frequently used source for value being subjective. This paper, however, only base this on a presentation at an LCI conference (Christoffersen, 2003, cited in Emmitt et al., 2005). In the context of value within Lean Construction this is, in the eyes of the authors, problematic.

This paper sets out by defining what value is on a fundamental level. This is done by stating nine tenets on the nature of value. The tenets presented in this paper are based heavily on Holbrook (1998), whose value typology is widely recognized (Sánchez-Fernández and Iniesta-Bonillo, 2007). Less recognized, but in our opinion, more important, is Holbrook's base definition of value and it's nature.

The paper starts out by providing an overview of the most relevant definitions of value, including the one outlined by Holbrook. Following this, nine tenets on the nature of value and the reasoning behind them are presented. Thereafter, we show how these can be combined into a coherent definition of value. Finally, we discuss the implications of the tenets for the understanding of value.

THEORETICAL FRAMEWORK

DIFFERENT VALUE DEFINITIONS

The concept of value exists in a plethora of different fields (Khalifa, 2004). Here, we review some definitions pertinent to value in the context of construction projects, notably from within economics, marketing and those employed within the LC community. Before considering different definitions of value, it is important to differentiate *value* from *values.* In contrast to the concept of values (plural), value (singular) is the outcome of an evaluative judgment (Holbrook, 1998). These two concepts are often confused (Sánchez-Fernández and Iniesta-Bonillo, 2007).

Value is a central concept within the field of economics. Economists traditionally refer value to utility or marginal utility when considering value and consumer behaviour (Bowman and Ambrosini, 2000). According to this, consumers spend their income to maximizing the satisfaction they obtain from products. Furthermore, total utility denotes the satisfaction gained from being in possession of a commodity, whilst marginal utility refers to the satisfaction that someone receive from getting one extra unit of a good, or the satisfaction lost by giving away one unit. Rooke et al. (2010) argue that these concepts are useful for studying the distribution of scarce resources, but of limited use to production science.

More relevant definitions of value can be found in the marketing literature. In a seminal paper by Zeithaml (1988), an exploratory study amongst consumers revealed four different understandings of value: *(1) Value is low price, (2) value is whatever I want in a product, (3) value is the quality I get for the price that I pay, (4) value is what I get for what I give.*

The two last definitions differ in that (4) considers all get and give components, while (3) only considers monetary cost and the direct quality of the product. Thus, this definition ignores other *give* components, such as the time and emotional costs required in acquiring the product, and *get* components, such as experience.

According to Zeithaml each of these definitions have their counterpart in trade or academic literature. She argues that all of them can be in one overall definition: *"Perceived value is the consumer's overall assessment of the utility of a product based on the perception what is received and what is given."*

Kelly (2004), analysing value management in construction projects, states that the most common definition of value in literature express value as the relationship between cost and benefit – essentially the same as expressed in definition (4).

The original Lean definition of value is generally considered to be that of Womack and Jones (1996), stating that *"value can only be determined by the ultimate customer. And it is only meaningful when expressed in terms of a specific product (a good or service, and often both at once) which meets the customer's need at a specific price at a specific time."* The first parts of the statement, addressing the question of value only being determined by the ultimate customer, concerns the subjectivity of value and who's value we should seek to maximize. The last part on the other hand, express the temporal dependence of value judgement. Ignoring these, what we then are left with is value being determined by the "*the customer's need at a specific price*". I.e. value is a function of the customer's fulfilment of his needs (how it benefits him or what he gets) and what he has to pay to get those needs fulfilled. If price is interpreted to include more than just monetary cost (e.g. time cost), then Womack and Jones definition corresponds to Zeithaml's fourth definition; *(4) value is what I get for what I give.*

Few of the value related papers presented through the IGLC include what we perceive to be any clear base definition of value. In about half of these, value is used as a term without it being properly introduced or defined. These typically use the concept of value is for introducing some kind of method or tool. Also, several having no definition of value address value generation. In the IGLC community, value generation theory from the TFV model (Koskela, 2000) can be seen as a starting point of the research on value, and research is widely influenced by this (Salvatierra-Garrido, Pasquire and Miron, 2012). However, Koskela mainly considerers the importance of delivering value from production systems and how they should be managed in order to do so (Drevland and Svalestuen, 2013). With regards to what value is per se, Koskela simply defines it as fulfilling the customers' requirements.

Some authors have employed definitions other fields such as marketing (e.g. Lima, Formoso and Echeveste, 2008) and economy (e.g. Andersen, Bølviken, Dammerud and Skinnarland, 2008). However, little of this has gained traction with the community at large. Of the papers that actually has anything that could be considered a clear base definition of value, the majority defines value in some way that could be said to correspond to Zeithaml's second definition of value; '*value is whatever I want in a product.*' E.g. Orrechia and Howell (1999) state that *"'What the client wants' defines value".*

The propensity to regard value as only concerning need fulfilment is also clearly evident in papers that refer back to Womack and Jones' definition, but only using part of it, most notably ignoring the price element (E.g. Whelton and Ballard, 2003). Another sign of this tendency can be seen in papers that employ the term 'value for money' when including the cost aspect of value (e.g. Bertelsen and Koskela, 2002; Orrechia and Howell, 1999). In these papers, 'value for money' is typically equated to benefit per dollar.

It is worth noting that economist consider 'value for money' the colloquial term for what they refer to as consumer surplus (Bowman and Ambrosini, 2000). Such analysts define the term consumer surplus as the gap between total monetary value and price, where total monetary value is the price the customer is willing to pay for the product based on his valuation of what he is getting. In other words, it does not denote what get you per dollar, but what you get above and beyond the balance point of give being equal to get.

Holbrook's (1998) definition of value differs from the ones presented so far. He defines consumer value *as "an interactive relativistic preference experience"*. According to our understanding of Holbrook, *interactive* refers to the value stemming from the *experience* of the subject interacting with the product or service in question. Furthermore, he states that *"such consumer value refers to evaluation of some object by some subject"*. Consumer value is thus not inherent in the product, but resides in the consumption experience. The *preference* part of the definition entails it involving a preference judgment between two or more options. Finally, *relativistic* relates to three elements. Value is *comparative* – involving preferences among objects; *personal* – varying across people; and *situational* – specific to the context.

Holbrook's definition covers several aspects lacking in the others. It has, however, some shortcomings that, in our opinion, prevent it from being a solid definition of value in the context of construction projects. Firstly, it is not particularly intuitive. The expression *"an interactive relativistic preference experience*" is rather obtuse, not helped by the fact that semantic elements can be said to be overlapping. 'Relativistic', for instance, includes a comparative element which equally can be found in the term 'preferential. Also, in the sense that sense that Holbrook uses it, 'an interactive experience' is somewhat of a tautology. *Interactive* signals something that one would actively partake in. In colloquial terms, most people would probably not consider sitting passively in a cinema watching a movie an *interactive* experience. However, according to how Holbrook defines the term, it is.

Overall, we consider the most the most significant weakness to be the omission of anything concerning the get and give aspects of value. This is to some degree covered in the topology part of Holbrooks work, but even there is barely touched upon. This has, in fact, been has been criticised by other authors (Sánchez-Fernández and Iniesta-Bonillo, 2007) .

Nonetheless, the following analysis leans heavily on the insight presented by Holbrook. The reason for this lies in its completeness, that is, its openness to the complexity of the notion. Rather than repeating Holbrook then, we envisage to deepen the analysis and strengthen the conceptual framework by identifying nine tenets through which the concept of value can be understood.

NINE TENETS

Value is a complex term. To mitigate some of the complexity, we examine different aspects of the nature of value on an atomic level expressed through nine tenets.

The word *value* has several meanings in the English language. The first tenet scopes the base meaning of the term and defines value at the most fundamental level. As such, is should considered an axiomatic statement upon which all of the other tenets are contingent. I.e. the other tenets are nonsensical if the first tenet is false.

T-1. Value is the result of an evaluative judgment

Values are different from value. However, values are important in the evaluative judgment. According to Schwartz and Bilsky (1987), there are five features common to most of the definitions of values found in literature, which they sum in a definition of values being *" (a) concepts or beliefs (b) about desirable states or outcomes (c) that transcend specific situations, (d) guide selection or evaluation of behavior and events and (e) are ordered by relative importance."* Thus, values will guide any value judgment:

T-2. Value is guided by values

An example of values in this sense could be "conserving the planet". This could lead to making greener choices for a building. However, such judgments require knowledge, both of the context and of the product or service being evaluated. In the case of greener choices, knowledge that global warming and such is a problem, and knowledge about how buildings contribute to this in general and specific knowledge about the solutions being considered. Said more succinctly, evaluation is based on knowledge (Lewis, 1946), leading us to the third tenet:

T-3. Value is dependent on knowledge

The values shaping this judgment belongs to someone or some entity. Holbrook (1998) refers to value being "personal". However, we feel that this term is inappropriate when considering value for an organizational entity like a company. Therefore the fourth tenet is given as:

T-4. Value is particular

An evaluative judgment is never performed in a vacuum. In the human psyche, value is intrinsically tied to decision-making (Kahneman and Tversky, 2000). How the concept of value is used in different fields highlight this. Anthropologists, for instance, typically use it as a means to understanding why do people choose to act as they do (Graeber, 2002), and for marketers it is a tool to understand and influence consumer purchase decisions. Such observations entail that value always concern choice, and comparing two or more alternatives to each other, leading to the fifth tenet of value, namely.

T-5. Value is comparative

What forms the basis of this comparison is debated. Various authors have offered different views on the subject. In the literature review leading up to this paper we found that, outside of the LC community, researchers generally agreed upon that both get- and give-components form a part of the value judgment. We would argue that if one accepts value as the result of evaluative judgement upon which decisions are made, then value is nonsensical unless *give*-components are included. This is expressed in the sixth tenet as:

T-6. Value can be decomposed into a set of get and give components.

How get- and give-components are evaluated, however, is contested. Sánchez-Fernández and Iniesta-Bonillo (2007), cataloguing the different approaches to perceived value in the marketing literature, distinguish value as a one-dimensional and a multi-dimensional construct. A multi-dimensional value construct means that *"value is an aggregate concept formed of several components",* while a one-dimensional value construct is a singular assessment. I.e. for the latter there may be several factors considered in the value judgment. Value is in this case, however, not the sum of its parts as the former suggests.

Based on this distinction, we would argue that value should be viewed as a one-dimensional construct. Value being a sum of its parts entails that each part could be evaluated separately and without consideration to the others. This would only make sense if value could be said to be linear. A notion that has been contradicted by Kahneman and Tversky (2000) in their seminal work leading up to Prospect theory. Thus, we formulate the eight tenet as:

T-7. Value is not summative.

Whatever the give and get components, we would argue that they always will be tied to experiences. E.g., one could consider a buildings aesthetics as a get-component. However, this is not inherently valuable. Its benefits stems from its ability to evoke emotions and influence state of mind in occupants, visitors and others. For an individual homeowner this could be an end in and of itself, for a company this will serve some higher purpose. E.g. Rybkowski (2009) shows how pleasing buildings facilitate faster patient recovery in hospitals. Humans will pursue experiences that enhance their quality of life; organizations will pursue experiences that will enhance their objectives (whatever they might be). This gives us the eight tenet:

T-8. Value is experience based

Some of the major get- or give-components will often be expressed in monetary terms, such as investments costs, maintenance cost or rent income. Can money be said to be an experience? Not directly. It is, however, a means to very many ends. Thus, it can be considered a placeholder for experience.

An important corollary to this is that during the value judgment not only the experiences gained from interacting with the objects in question are considered, but also potentially gained or lost experiences outside of the scope of what is being evaluated. E.g. if an owner chooses to put more money into a construction project to improve some aspect of the building, he will at the same time forego the option of investing the money elsewhere with the accompanying experiences from that. What other options are available depends on the context. Corollary proof to this can be found in what Soster et el. (2014) calls the *bottom dollar effect*. For consumer purchases, the perceived monetary sacrifice is greater when available funds are low, leading to a lower satisfaction, i.e. perceived value.

Holbrook (1998) refers to this as value a being *situational*. We choose to express the ninth tenet as:

T-9. Value is context dependent.

We believe the nine tenets presented here are universal and applicable to any situation where the word *value* is understood to mean something in line with the first tenet, that is, value is the result of an evaluative judgment. Based on the tenets and the discussions around them we can arrive at the following definition of value:

> *Value is the result of an evaluative judgment. This judgment is guided by values and based on the evaluator's knowledge at hand. It is always based upon comparing two or more alternatives in a given context. This context envelops all get and give consequences for a particular party from a decision made on the basis of the value judgment. The get and give consequences are always in the form of gained or lost experiences, or expressed in monetary terms as a*

placeholder for experiences. The consequences are not summative, the value judgment is done by considering them all at once.

IMPLICATIONS FOR VALUE RELATED CONCEPTS

VALUE FOR WHOM

Value is particular. Whose particular value we should concern ourselves with in construction projects is a complex matter. Different authors have offered different opinions on the matter. E.g. Salvatierra-Garrido et al. (2012) have argued that the value for the wider society has to be considered while Drevland and Svalestuen (2013) argue that only the value for the paying client is of consequence. According to Bertelsen and Emmitt (2005) we need to consider the client as a complex system. It is beyond the scope of this paper to fully tackle this subject. However, some reflections are warranted.

The first tenet states that value is a result of an evaluative judgment. This implies that there has to be a judge (or a panel of judges acting in unison). If we go beyond considering the client as single point this becomes challenging. If no judge is formally appointed, the project manager, architect, or whoever is handling the value management process, will be in a position of *de facto* judge. We would argue this is not something anyone in such a position should do on their own volition, at least without clear guidance from the customer. Thus, on any construction project there should a clear notion of who is the supreme value judge.

PERCEPTION OF VALUE

Some authors argue that all value is perceived value, and that any concept of true value is nonsensical. This might be true if considering value through a marketing lens. The core concept of marketing is the transaction (Kotler, 1972). Arguably, this implies that the focus is on one customer making a buy-or-no-buy decision based on the value perceived at a single point in time. Thus, perception is everything.

Conversely, in construction the concern should be delivering actual value over time. The buy-or-no-buy decision is typically made long before the value to be delivered has been decided in detail. In this context, true value can be a very usable concept. To define true value we first need a definition of perceived value and define it as:

Perceived value *– The value of something for the perceiver. How a product or service is evaluated by someone will depend on their values and the knowledge they possess*

When defining true value, the salient point in the above definition is the one based on the seventh tenet, that value is dependent on the evaluator's knowledge at hand. Logically, flawed knowledge will lead to a flawed perception of value.

Perfect information is a concept originating in game theory. McConnell (2000) defines it as ”the state of knowing everything there is to know about a specific problem or decision situation.” However, information and knowledge are not the same. Information is raw data. In an evaluative situation, knowledge entails understanding the consequences of that data. We therefore propose to define true value as:

True value *– The value that would be perceived if the perceiver had perfect knowledge.*

The relationship between knowledge and information is expressed by Brookes' (1980) in his fundamental equation: $K[S] + \Delta I = K[S + \Delta S]$. When information is added, a knowledge structure will change to a new modified structure. According to Bawden (2011) this equation is *"a description of the information communication process as it affects one individual's knowledge*". The effect of the information may vary according to the knowledge structure to which it is added. One consequence of this is that past experiences and corollary knowledge will greatly impact someone's ability of translating information into usable knowledge.

Maia et al. (2011) argue that it is impossible for someone to accurately predict the evaluation of someone else. This might be, since this also would entail accurately predicting the knowledge they possess. However, we would argue that someone who is sufficiently knowledgeable about someone else and their situation, might be able to give an estimate of the value of a product or service for them that is closer to the true value for them, than what they themselves perceive the value to be. Case in point, an industry practitioner will most likely be better able to gauge a buildings' fitness for purpose than a (non-professional) client. This due to being better able to translate the available information into relevant knowledge. Based on this we define estimated value:

Estimated value *– The value for someone estimated by someone else. Value is always seen from the point of view of someone, but can accurately be estimated by someone else if the estimator is sufficiently knowledgeable about the values of the subject he is estimating the value for and their context.*

WASTE

Waste is a central concept within LC, closely tied to that of value. Without a tangible concept of value, waste is even more intangible (Bertelsen and Emmitt, 2005). Womack and Jones (1996) define waste as any activity that consumes resources and creates no value. If Value=Benefit, however, any activity that produces even the slightest amount of benefit is not waste, no matter how large the monetary costs or other sacrifices required to obtain the benefit may be. Conversely if value is defined as Value = Benefit – Cost, then any activity where the cost of performing it outweighs the benefits created from it would be considered waste. This is therefore a much more sound definition of value in the context of waste.

Considering only the benefit side of value might be sufficient when considering construction. Construction activities can be considered to be more or less binary in nature, in the sense that if an activity adds value, then it is required to yield the specified end-product, no matter how much it may cost to perform it. E.g. if the building design specifies a column then that column has to be built, or the building will not be usable. Design, however, is an iterative process, where a marginally better solution always can be found (Meland, 2000 cited in Drevland and Svalestuen, 2013). The placement and design of said column will affect load bearing capacity, material usage, and flow of people in the building amongst other things. However, at some point in time the cost of finding this marginally better solution will outweigh the benefits of it. By employing a definition of Value = Benefit - Cost, doing so would be considered waste by definition.

CONCLUSION

We would argue that the nine tenets, taken together as a definition, is not only more complete than previously presented definitions, but can also be said to envelop all of them with one important caveat. This analysis thus present a much wider view of the comparative aspects of value than others do. E.g. Zeithaml (1988) describes situations where customers consider one product to be superior to the other, but choose the lesser product due to monetary restrictions. In our opinion, however, this fails to bring in the loss or gain of experiences outside of the direct scope of the product or service being considered. An implication of this is that going by the definition outlined in this paper, whatever choice is made in a decision situation, is the one that was perceived as having the highest value by the evaluator at the time the evaluative judgment was made.

At first glance, it might be difficult to see how we could claim to envelop the benefit only views of value. However, we would argue that formulations such as ‘what the customer wants’ is in reality a simplification. This ‘want’ is the result of a value judgment that necessarily also take sacrifice into account. At least if we consider ‘want’ outside of the context of wish lists and letters to Santa Claus; or a situation where the customer has so much time, money, or other sacrificial resources that the perceived sacrifice is negligible in the given context (i.e. a wealthy person buying Heinz brand beans over the store brand). In the context of construction projects, neither of these are really applicable. However, ‘what the customer wants’ could entail that even though the sacrifice is not explicitly formulated or mentioned, it lies there implicitly. I.e. what the customer wants is contingent on getting it at a price where the perceived cost is lower than the perceived benefit.

Although the above definition might be complete, it is not compact. In most situations, it is too voluminous to be practical. Therefore, it will often be better to use simplified versions, such as saying that value is what the customers wants. However, this should be with the understanding that all of the tenets described would still apply.

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LEAN CONSTRUCTION AS AN OPERATIONS STRATEGY

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ABSTRACT

All companies have an operations strategy; a pattern of decisions made in operations with the purpose to support the business strategy. Lean Construction can be seen as an operations strategy. The aim of this research is to present the generic decision categories in an operations strategy and discuss their characteristics in contrast to the Lean Construction framework. A literature study identified ten decision categories: process technology, capacity, facilities, vertical integration, human resources, organization, quality, production control, product development, and performance measurement.

Data was collected through in-depth interviews with managers on the tactical level at three construction companies with a Lean implementation. The results indicate that Lean construction companies emphasize quality, production planning, and vertical integration in their operations strategy. Facilities, process technology, capacity, and organization receive less attention. Quality, production planning, and vertical integration are keywords also in Lean Construction, while it is intriguing that organization receives little attention. Facilities, process technology, and capacity are ever changing between construction projects and are candidates for decision categories that could be less relevant for formulating an operations strategy in construction.

KEYWORDS

Operations, process, production, production system design, strategy.

INTRODUCTION

Construction projects are executed by temporary organizations assembled to deliver a specific artifact to the client, while the contractor firm is a permanent organization designed to organize projects (Winch, 2014). The contractor firm and the projects have an overlapping interest in the firm resources. Like every firm, a contractor must have a business strategy and an operations strategy, Figure 1. The business strategy frames *what* products and on what market (*where*) this will be offered. An operations strategy is a long-range plan for the operations function (Anderson, Cleveland and

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Schroeder 1989). The operations strategy, (Skinner, 1969), frames *how* operations should be conducted to support the business strategy (Boyer and McDermott, 1999). It is the guiding idea on the tactical firm level, and is often emergent; traceable as a pattern of decisions (Slack and Lewis, 2011).

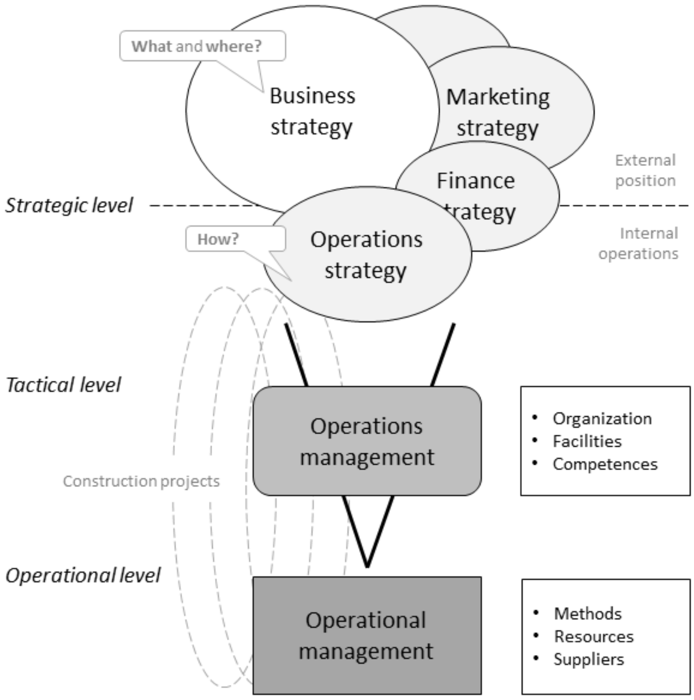

Figure 1: Links between business and operations strategies in a single-business firm.

Lean Construction, (Koskela, 1992), can be perceived as an operations strategy (Slack and Lewis, 2011). Hayes (1985) stated that operations capabilities can even determine the business strategy, especially in environments that are difficult to forecast. Porter (1996) contends that operational effectiveness is necessary but does not suffice as a business strategy. Successful operations interact with the business strategy and the business model of the firm (Brege, Stehn and Nord 2014; Pekuri, Pekuri and Haapasalo 2014). The situation in construction is often highly changeable and difficult to forecast, thus analysis of contractor firms' operations strategies should provide interesting indications about how they balance engagement in temporary projects with permanent survival.

The aim of this research is to identify published characteristics of typical operations strategies (in terms of decision categories) and compare them to emergent decision categories in Lean Construction. A literature study displays the elements of operations strategy and Lean Construction. Furthermore, the operations strategy at three Lean construction contractor firms was explored by investigating the types of decisions prioritized by tactical level managers.

FRAME OF REFERENCE

OPERATIONS STRATEGY

The idea that manufacturing affects business strategies was first put forward by (Skinner, 1969). In strategy literature a similar concept is labeled the resource-based view, advocated by Barney (1991). While the resource-based view addresses capabilities on a firm's strategic level, an operations strategy formulates how resources are to be used on the tactical level. When forming an operations strategy, aspects of firms' resources and their environment related to several decision categories should be considered. Rudberg and Olhager (2003) compiled a list of decision categories mentioned by various authors, as summarized in Table 1.

Table 1: Decision categories condensed by Rudberg and Olhager (2003)

Structural categories	**Infrastructural categories**
Process technology – *the choice of production method*	Human resources – *availability and competence of human workforce*
Capacity – *amount of work that can be completed in an operation*	Organization - *the relations among staff, functions, responsibilities and processes within a firm.*
Facilities – *in construction most often the building site*	Quality - *the degree to which customer requirements are fulfilled. In construction, there is a sequence of customers in the supply chain.*
Vertical integration – *long term relations with subcontractors*	Production planning and control - *the methods applied to manage production*.
	Product development - *the development of new solutions that renew client offers.*
	Performance measurement - *methods to evaluate if an organization is performing as intended (coupled to the business strategy).*

Decisions in each category are made when starting a new business unit or changing the direction of an existing unit. For an operations strategy to yield good performance there must be consensus among the individuals in a firm, (Boyer and McDermott, 1999). Consistency between the operations strategy and business strategy is essential, (Wheelwright and Hayes, 1985). As new decisions are made to enhance the operations strategy, its relation to the business strategy can be strengthened.

The decisions made in daily operations are handled through operations and operational management, Slack and Lewis (2011), focusing planning, execution and quality control of work tasks, Figure 1. Hjelmbrekke and Klakegg (2013) claim that many contractors use the productivity gained through efficient operational management as part of their business strategy, while they should focus customer value (c.f. (Koskela, 1992)). Aligning each construction project's strategy with the overall business strategy is an action to ensure project success both for the client and the contractor (Cooke-Davies, 2002). The operations strategy must serve multiple concurrent projects, while operations and operational management can focus a single construction project. The operations strategy is an important mediator to unite operational (project) and strategic levels, supporting (Haugbolle and Forman, 2011).

LEAN CONSTRUCTION

The ideas of lean production were brought to construction by (Koskela, 1992) through noting the peculiarities of construction: one-of-a-kind site production realized by temporary multi-organizations. The basic concept to grasp for leaders in a Lean construction firm is that production consists of flow and conversions of material and information, gradually adding value delivered by the supply chain, (Koskela, 1997). The guiding principles in Lean construction describe how to improve production performance e.g. reduce variability, increase process transparency or simplify (ibid). The principles are realized through methods as JIT, concurrent engineering, or Last Planner (Ballard and Howell, 1998). Howell and Ballard (1997) pointed out that there is great uncertainty at the beginning of construction projects, which distinguishes construction from manufacturing. They even claimed that 'construction is essentially a design process', which is explained by the engineer-to-order supply chain structure of construction, (Johnsson, 2013). The design process is: 1) A production process (of information) with a flow, which can be improved using Lean Design Management (Koskela, Ballard and Tanhuanpää, 1997) and 2) A product development process improvable and decomposable through the application of e.g. the Design Structure Matrix and derivatives (Furtmeier and Tommelein, 2010).

Howell and Koskela (2000) summarised the development during the first 8 years: 'lean construction is a development where lean production has been taken to the project environment'. Several methods have been developed, useful to successfully manage construction projects, where the foremost is the Last Planner system (Ballard, 1994); a method that is robust in the turbulent flow of construction (Bertelsen and Koskela, 2004). Stability in the supply chain flow was sought by e.g. proposing logistics centres (Arbulu and Ballard, 2004) as an answer to the call 'construction must develop supply chain management in its context' (Vrijhoef and Koskela, 1999).

Site production calls for workplace planning (Pennanen, Whelton and Ballard, 2004). Breaking down the workplace in several zones and allocating resources to them, supports the search for 'takt' in the construction project (Frandson, Berghede and Tommelein, 2014). Human resources in construction are very important as they constitute much of the production capacity due to little automation in construction. Humans are carriers of knowledge in an organization and also between projects. A hindrance for knowledge transfer and joint learning through experience feedback is the construction trades (Bertelsen, 2001). Allocating resources between projects is a typical work task for a construction manager on the tactical level (O'Brien, 2000).

LEAN CONSTRUCTION AS AN OPERATIONS STRATEGY

Etges et al., (2012) categorized the practices in the IGLC community, Table 2. A comparison was made with Table 1 to check for topics that overlap and the result is shown in Table 2 (with reservation for different interpretations). Table 1 mentions a few categories that are not part of Table 2: process technology, capacity, and organization. Furthermore, Table 2 reports some categories that are not part of Table 1 as continuous improvement and flow. These categories concern running of the business, not redirection.

Slack and Lewis (2011) explained Lean production principles in relation to some of the decision categories:

- Capacity means sacrificing high resource utilisation for fast and dependable output
- Supply network means synchronising flow with suppliers and expecting them to improve continuously

- Process technology should be small, flexible technology that reduces process variability
- Development and organisation should rely on continuous improvement through waste reduction where a smooth flow exposes the waste

What Slack and Lewis (2011) did with this exercise was to identify not what the operations should do, but how operations shall be conducted i.e. they concluded that Lean is an operations strategy.

Table 2: Identification of decision categories in Lean Construction

Topics at IGLC	[%]	In Table 1	Comment
Production planning and control	18%	√	
Design and product development	16%	√	
Supply Chain Management	10%	√	Vertical integration
Human Resources	9%	√	
Information technology	9%		
Continuous improvement	8%		
Workplace layout	6%	√	Facilities
Standardised work	4%		
Visualization and performance	4%	√	Perf. measurement
Safety and sustainability	3%		
Pull	3%		
Continuous flow	3%		
Cost	3%		
Quality	2%	√	

Researchers have identified the need for consistent leadership for Lean Construction to be successfully implemented e.g. (Keiser, 2012). For construction it is important to distinguish between the leadership tasks in projects, which can benefit fully from methods and approaches developed for projects (e.g. Last Planner) and the leadership tasks on the tactical level, which encompasses how to manage several projects while aligning with the business strategy and how to manage cultural change during Lean implementation. On this level, Lean Construction provides less support as it is mainly a strategy for operating projects (Howell, Ballard and Tommelein, 2011).

METHODOLOGY

As the operations strategy is frequently implicit, in-depth interviews focused on decision categories and their prioritization were conducted. The research does not attempt to formulate an operations strategy for the construction industry; rather the intention is to elucidate possible constituents and priorities of operations strategies. The limited number of interviews renders indicative conclusions.

DATA COLLECTION

Empirical data was collected through interviews with a tactical level manager at each of three different Lean construction contractors in Sweden, Table 3. The selection of respondents was based on their position in the contractor firm and their long-term experience of enacting their respective firms' operations strategy. Respondents were selected from different contractors to increase the external validity of the results.

Table 3: Respondents.

Respondent	Position at firm
D	Lean manager, reporting directly to top management, liable for process improvements of 10 M€
E	CEO, liable for a turnover of 3.5 M€
F	Platform manager, part of top management, joint liable for a turnover of 1300 M€

The interviews were semi-structured and about one hour long. All interviews were recorded, fully transcribed and the texts were used as the basis for the analysis. The respondents received transcripts of the interviews for approval. Both authors are active professionals in both academia and the construction industry. This was advantageous for understanding the language and expressions used for naming and attributing objects when interpreting the interviews. A disadvantage with being socialized in construction is the risk of regarding an issue as being settled before it is actually fully understood. Another risk lies in interpreting statements as they appear in our own, rather than the respondents', frames of reference.

ANALYSIS METHOD

All the transcripts were read by both authors, and meanings of decision categories (Lidelöw and Simu, 2015) were defined in terms of the construction context. The statements in the interviews were coded according to 10 defined decision categories, Table 1. The authors conducted this analysis separately to increase the internal validity of the findings. The results of the coding are presented in Figure 2, where the size of the squares indicates the proportion of time spent by each respondent talking about a certain decision category (taking due care that the respondents were actually discussing the decision category, not trying to understand or question it).

INTERVIEW RESULTS AND ANALYSIS

Illustrative comments from the interviews are presented in Appendix A1. Although the Appendix contains many comments in almost all decision categories, it does not provide a fair overview of the actual emphasis put by the interviewees on them. In Figure 2, the emphasis is visually displayed.

From Figure 2 it is evident that *Quality* is a major concern in operations for the respondents at the Lean construction firms. Standardization and strive to repeat processes were reoccurring topics. 'We try to focus on the 90% that we can standardize, not the 10% that we cannot', Lean manager, company D. Standardised work and quality sum up to 6% of the topics in IGLC papers (Table 2), which does not reflect the emphasis in the interviews. This can be due to differing interpretations of the definition of quality.

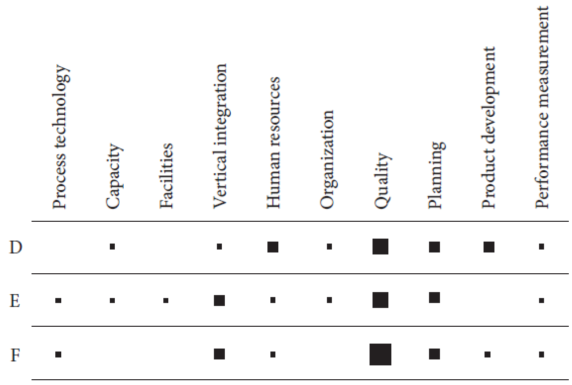

Figure 2: Graphical representation of interview results. Larger squares indicate larger emphasis by respondents.

Planning is another category that attracts great interest from the respondents. Arranging meeting arenas (daily meetings, rooms) and making schedules with varying level of detail are two activities that are used. In Table 2, planning is the largest category (18%) where developments around the Last Planner system dominate. Firms D and F both have variants of the Last Planner system in place. 'We use time sheets, running 5 week schedule, weekly schedules and daily control', Platform manager, company F.

Vertical integration concerns the supplier network and the relation to subcontractors. Supply chain management is addressed in 10% of all IGLC papers (Table 2) and is identified by Slack and Lewis (2011) as one of their four decision categories for an operations strategy. 'When we started with Lean, we brought in our subcontractors from the onset', CEO, company E.

Managing *Human Resources* entails the pedagogic challenge to show people how they should act and respond to actions around them. The respondents identify leadership as an important factor along with the actions leaders take. Human resources are brought up in 9% of IGLC papers, even though leadership is not explicitly mentioned in Table 2.

Product development is a decision category that attracts much attention in the IGLC community (16%). It is not mentioned by the respondents very often, but is seen as a way to enhance the client offer. Product development is linked to continuous improvement through sharing the PDCA-cycle. *Performance measurement* is mentioned by all respondents, mostly in terms of takt time. Table 2 labels categories differently: performance measurement could be part of visualization and performance, but also continuous flow and production control.

Process Technology, *Capacity* and *Organization* attract the same (quite low) level of interest from the respondents. Neither of these decision categories is mentioned in Table 2 as strongly represented in the IGLC community. However, they are all put forward by Slack and Lewis (2011) as three of the four decision categories to consider (the last one being *Supply Network*). One should note that Slack and Lewis (2011) developed their framework for the manufacturing industry in general.

Facilities attract the least attention of all the decision categories from the respondents. Workplace layout is addressed in 6% of the IGLC papers. Rudberg and Olhager (2003) put forward facilities and the physical planning of them as decisive for the formation of an operations strategy in manufacturing.

CONCLUSIONS

As an operations strategy is the pattern of decisions made on the tactical level, using decision categories can help identify the decision topics. The decision categories presented by Rudberg and Olhager (2003) all emerged from the three interviews with construction managers. *Quality*, *Planning, Vertical Integration*, and *Human Resources* are prioritized by Lean Construction firms. *Capacity*, *Organization*, and *Process Technology* attracted much less interest from the respondents. The topics hitherto covered in the IGLC community overlap with 7 of the decision categories suggested by Rudberg and Olhager (2003): *Process Technology*, *Capacity*, and *Organization* are missing in Table 2. *Process Technology* and *Capacity* could be logically explained since construction is realised through subcontracting to a large extent. *Organization* is more surprising not to find – perhaps this is a reflection of the topics in the IGLC community revolving around improving the project (Figure 1 lower part) and has yet to address the firms that manages the projects (Figure 1 upper part). This research will continue with a search for decision categories relevant to construction.

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LEAN CONSTRUCTION THEORY AND PRACTICE: AN IRISH PERSPECTIVE

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ABSTRACT

Ireland is emerging from a deep recession following a 75% reduction in Architectural, Engineering & Construction (AEC) output, causing reduced demand, employee redundancies, workforce emigration and company closures. This paper proposes Lean Construction (LC) as an antidote. However, LC theory is not widely taught in Irish universities and field research and case studies are very limited – sector research is 0.002% of industry research expenditure. LC is in its early stages in Ireland and is gaining momentum thanks to the Lean Construction Institute Ireland (LCII) Community of Practice (CoP). This paper looks at professionals understanding of lean and LC and compares LC theory with current practice. Research was gathered through a literature review, three surveys (n=48; n=42; n=116), three focus groups (n=22) and eight interviews (six expert) and was analysed through NVivo Computer Aided Qualitative Data Analysis Software (CAQDAS). The main findings show that LC theory does not compare strongly to practice. However, lean tools in large companies (200+ employees) appear widespread. While LC is far from commonplace, practitioners are focused on "wins" and "proof" rather than the management philosophy that is LC. Future education, training and increased research will show a different perspective – practice relating more strongly to theory.

KEYWORDS

Lean, lean construction, theory, Community of Practice, thematic analysis

INTRODUCTION

This research began in 2012 following a long, tough recession which hit the Irish AEC sector, resulting in a 75% reduction in output, peaking at €38.1 billion in 2006 (23.8% GNP) which reduced to €9.4 billion in 2013 (6.6% GNP) causing a 65% reduction in direct construction employment (DKM, 2015). Participants to date have

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included a broad range of national and international AEC professionals. This paper focuses on professionals' understanding of lean and outlines the research carried out to date including the initial findings from primary and secondary research in Table 1. These findings are presented for further discussion by the IGLC community.

The concept of lean is not new having been around over 25 years (Liker and Rother, 2014). While lean manufacturing is more common, LC is only beginning to take a foothold. However, in Ireland, LC is gathering interest and momentum. Much of this can be attributed to the collective effort to raise awareness and promote LC since 2013 by LCII CoP and the wider community including CITA (Construction Industry Technology Alliance), CIF (Construction Industry Federation), CIL (Construction Innovation Lab) and Dominic Greensmith and John French from the Intel Ireland Construction Management Team. Since 2014, articles to promote LC and the LCII CoP were published in journals, trade magazines and newspapers by Ebbs, Egan and Turner (2014); Ebbs and Turner (2014); Foley (2014a, 2014b); Intel Newsroom (2014a, 2014b); Lehnane (2014); McNieve (2015) and Walsh (2015).

THE IRISH AEC SECTOR

The Irish AEC Sector has experienced tremendous growth followed by extraordinary reduction over the last decade. During times of growth, waste was masked by the abundance of work and plentiful resources. The Irish banking crisis together with the over-production of residential units resulted in many ghost estates and bankrupt AEC companies during the recession. Dissatisfaction with the status quo of the Irish AEC sector was evident. Time for change was ripe. By illustrating the extra value and attraction that lean thinking can bring to the Irish AEC sector, export potential and opportunities for native Irish AEC companies providing products and services in other markets – especially the UK – will be boosted. Additionally, this will attract increased foreign direct investment (FDI) in line with Intel's $5 billion investment announced for Ireland in 2014. There is a "win-win" scenario if the Irish AEC sector adopts lean "together". The more value for money (VfM) the AEC sector can deliver, the greater the amount of FDI that can attracted, thus growing the AEC sector again.

Lean Construction Institute Ireland (LCII) Community of Practice (CoP)

The LCII CoP was established in April 2014 by a core group of volunteers committed to improving the way capital projects are planned, designed, delivered and operated. The LCII Vision is to make Ireland a centre of excellence for LC. The mission statement states: *"lean thinking will benefit the Irish construction industry and wider economy and the LCI CoP is the way to deliver it."* The primary aim of the CoP is to encourage the adoption of lean into the Irish AEC sector by raising awareness of LC philosophy, principles, and practices and also provide a platform for companies to share their direct experiences of why and how lean just "works". Seven events have taken place since April 2014 with over 1,300 attendees. The LinkedIn "Lean Construction Ireland" Group has grown steadily since April 2014 and currently has 1,162 members. To date, LCII has been publically endorsed by Enterprise Ireland for the efforts made to improve both the Irish AEC sector and the competitiveness of Ireland Inc. Keegan (2015) stated *"by taking the lead in lean construction, the LCI Ireland CoP is providing an invaluable support to the sector to help it adopt and adapt best practice to ensure sustainable development."* Commenting after the 5th CoP event, Shaw (2015) described the 260 delegates as *"the most engaged and* *attentive construction audience I have spoken to… there is much that the wider western European construction sector could learn from the Irish intent and drive to remain competitive."*

LEAN THEORY

The term 'lean' has been around for 25 years (Liker and Rother, 2014). However, there has been a shift in how the theory has been applied in practice during that time (Liker, 2014a). Rother (2010) detailed in "Toyota Kata" how the management of organisations has changed over the past 60 years and stressed how we need to move from Managing by Objectives (MBO) – or results – to Managing by Means (MBM) – the capability of people. Luckman (2014) added the need to move from *"doing lean"* (using tools to reduce waste) to *"becoming lean"* (people and problem solving centric).

Construction theory combines Transformation, Flow and Value (TFV) theories with each being complementary rather than contradictory. Their practical application is task, flow and value management. Furthermore, projects need to be treated as production systems. (Koskela, 2000)

How people, think, act, communicate and learn in a system is critical. If you want to know how to fix something you must understand how it works. Therefore, if you are going to use LC sustainably, both the theory and what lean means for each stakeholder needs to be understood. Lean means different things to different people depending on their perspective to a situation - similar to "value."

What lean is not?

Before looking at what lean and LC are, it is important to understand what lean is not. Lean is not best practice but better practice. It is not a quick fix, it is a journey of lifelong learning and continuous improvement. Lean is not a silver bullet or a magic wand – effort and buy-in from all levels is required. Nor is it a car wash, you cannot just run your company through a lean training programme and come out the other side claiming to be "lean", otherwise known as "Hollywood Lean" or lean for show. LC is not just a set of tools but is a paradigm shift how capital projects are planned, designed, delivered and operated. Lean is not a tool to cut jobs, it is a philosophy used for company growth and expansion through the development of people and processes.

What is lean?

There is a myriad of definitions of lean. Keegan (2011, p.2) maintains "*lean starts from the point of knowing what a customer wants, values and needs. It then works to find the best way to deliver that to the customer."* Likewise, Liker and Rother (2014) cited a "first definition of lean" from the February 2014 edition of Quality Progress: *"lean is the permanent struggle to better flow value to each customer."* Mossman (2014) stated *"lean is a philosophy, a way of thinking about the management of work in projects."* However, he drew caution to defining it too closely as two things can happen - *"you create schisms and you alienate people, and stop innovation… as soon as you create schisms the community falls apart and the community is critically important."* Liker (2014b, p.32) defined lean as *"a strategy for Operational Excellence based on Clearly Defined Values to Engage People in Continuously Improving Safety, Morale, Quality, Cost and Productivity."* Trachilis (2014) posits *"lean is about an entire organisation living the core values of that organisation to* *improve safety, productivity, cost, quality and human resource development. Living the core values is key, with a focus on True North."* Both Liker and Trachilis argue that one cannot use the elimination of waste as the singular strategy to a successful company. This concurs with Keegan (2014) who said *"I take a non-traditional definition to lean. I understand lean is about pull and it's about standardisation and about all those good things. To me lean is all about building the capability and capacity of people and processes using good practice."* Ebbs (2011) cited Cooke and Williams (2009) who defined lean as *"the elimination of waste from the production cycle".* While this is not technically incorrect eliminating waste only relates to the "Flow" element of TFV theory (Koskela, 2000). There are many other nuances to lean which equate to far more than eliminating waste. Howell (2013) described LC as *"a new way to see, act and understand the world."* Howell (2014) added that *"lean is a management philosophy supported by a coherent set of conceptual foundations, basic principles, fundamental practices and a common language".*

In other words, lean is a term that relates to a proven way of doing business, entirely focused on maximising customer value through relentless elimination of all forms of process waste and ensuring that value-adding activities in the value stream are completed in the most efficient and time-effective manner. Keegan (2014) referred to a counterfactually econometric analysis on the impacts of Enterprise Ireland's Lean "Start" "Plus" and "Transform" programmes on the companies involved. What they found was a 20% increase in productivity which was equivalent to a €660 million annually delivered in addition to an 11% increase in employment (6,000+ jobs) across these companies - clear evidence that lean is a mechanism for growth and expansion not job losses. Umstot (2014) described lean as *"a transformation in the way you approach and think about the way you deliver your work and is not just about eliminating waste or just about creating value, but it's a mind shift, which will allow you to look, listen and learn and basically continuously improve through a set process."* Put simply, Keegan (2014) defines lean as *"Better, Faster, Cheaper…Together."* Akers (2012) argues that *"lean is simple: fix what bugs you."* However, Christian (2014) added that *"lean is the hardest simple thing you will ever do."* Ballard (2014) maintains that the purpose of lean is:

- to optimise the whole project not the piece;
- to transform management to facilitators - a manager in a lean system is there to 'teach & coach' not lead;
- to get more 'value' for owners';
- to provide more profit for contractors' and designers';
- that it makes people want to come to work.

RESEARCH METHODOLOGY

AIM AND OBJECTIVES

The aim of this research is to identify how the theory of Lean Construction (LC) compares with current practice in the AEC sector. The objective is to investigate and examine professionals understanding of lean and LC theory.

DATA GATHERING

The primary data was gathered through a mixture of 80 hours observational research, three surveys (n=42; 48; 116), three focus groups (n=22) and eight interviews.

The observational research was spent between three construction sites shadowing management to remove any biases and to establish if the researchers own experience expending resources "fire-fighting" was reflected by others. It was shown to be the case. Two surveys relating to Building Information Modelling (BIM) being 'the' tool to implement LC identified that respondents understanding of LC and BIM is not succinct. These were sent to the Irish market (n=48) and US Academics (n=42). The survey results helped form the basis of the questions for three focus groups that took place before a guest lecture by Howell (2013). The same questions were asked to each group and subsequent interviewees (n=2). The questions were semi-structured but focused on:

- What is your understanding of lean?
- Is there a need for lean in the Irish AEC sector? Could you explain your answer?
- What is the value of introducing lean into the Irish AEC sector?
- How could we embed lean into the Irish AEC sector?
- What challenges might arise if embedding lean into the Irish AEC sector?

Six expert interviews were undertaken to triangulate the responses of the other participants and the literature. The main questions mirrored above, but they were asked:

- How do you define lean?
- How have the attitudes to LC in the US/UK changed in the past 20 years?

During the interviews, themes that emerged included the Community of Practice, the promotion of LC (getting the message out there), motivation, and the effect of lean on employee wellbeing (H&S), employment and attrition. Another survey which was conducted at the launch and inaugural event of the LCII CoP in 2014 (n=116) by Egan, Tolan and Ebbs (2014) identified the use of lean tools in companies with 200+ employees is widespread.

DATA ANALYSIS

A thematic approach was chosen to analyse the qualitative data in conjunction with NVivo Computer Aided Qualitative Data Analysis Software (CAQDAS). Systematically and thematically sorting the data into codes allows appropriate data analysis to be conducted, condensed and generalised into specific codes (Naoum, 2007).

Thematic Analysis

Braun & Clarke (2006) defined thematic analysis as the search for patterns or themes in a defined set of data. It is a qualitative analytic method. They advocate in regard to qualitative research that thematic analysis is a useful and flexible method of analysis. Ryan and Bernard (2000), Boyatzis (1998) and Holloway and Todres, (2003) all argue that thematic analysis should be used as part of a broader qualitative study. However, Braun and Clarke (2006) maintain that thematic analysis is a method on its own similar to grounded theory but with fewer complexes. Braun and Clarke (2006) analysis consists of six stages to analyse qualitative data from the observations, surveys, focus groups and interviews. The stages are 1) transcribing and reading over interview notes; 2) generating initial codes; 3) searching for themes and developing sub-codes; 4) reviewing themes; 5) defining and naming themes; and 6) producing the report.

Coding

Braun and Clarke (2006) argue that thematic analysis supports a flexible theoretic approach towards analysing qualitative data and that there is no right or wrong approach. An inductive or theoretical approach can be taken or indeed a combination of both. The inductive approach is otherwise known as a 'bottom up' method and the themes will be heavily linked to the data – similar to grounded theory. On the other hand the theoretical (deductive) way is driven by the researchers experience with theory and helps to provide a more detailed analysis. This research combines both inductive and deductive methods. The coding was divided into four main themes: Challenges (12/616), Drivers (13/545), People (12/723) and Embedding (13/844). The first number in the brackets relates to the sources including surveys (n=2), focus groups (n=3) and interviews (n=8). The number of references to each theme is the second number in each bracket. These themes were then subdivided into 219 sub codes. Table 1 outlines some of the codes that were generated and the analysis of qualitative data. Where applicable, the number of sources and references are shown in brackets on the right of Table 1.

INITIAL FINDINGS

Initial findings (outlined in Table 1) suggest LC theory does not compare strongly to practice and the participants understanding of LC mainly focuses on eliminating waste, adding value and continuous improvement. There is much more to LC than this which concurs with Umstot (2014) who stressed *"the more you know about lean the more you realise there is to learn".* Many nuances and soft skills associated with lean appear to be neglected in favour of the participants need for certainty (proof/evidence) before they will commit to becoming lean (change). It appears that participants favour easy wins and tick the box solutions that produce results (20th Century lean) over "real lean" (21st Century lean). Table 1 synthesises the analysis of literature and primary data (observational research, surveys, focus groups and interviews - including thought leaders). It illustrates inconsistency between lean theory and current practice. The left column shows how the theory applies, while the right column captures the reality or people's perceptions of the application of lean and LC. Table 1 is divided into six broader codes: Principles; Pillars; Culture; Contracts; Understanding and Project Goals. This paper concentrates on professionals understanding of lean and LC theory and how this compares to current practice. Further research and data will be gathered through semi-structured interviews and observational and ethnographic research. A year spent training, coaching and facilitating teams involved in the procurement, design and construction of capital projects in the USA will form the basis of future research.

Table 1: Summary of research - lean construction theory versus practice

Theory	Feature	Current Practice
Transformation Flow Value (stream) Standardise (task) Waste Visualisation Perfection	**Principles**	1. Waste (12/145) 2. Value stream (12/118) 3. Value (12/111) 4. Perfection (12/103) 5. Standardise (7/136) 6. Flow (9/34) 7. Visualisation (2/5)
Theory	**Feature**	**Current Practice**
H&S Quality Sustainability Time Cost	**Pillars**	1. Cost (11/166) 2. Time (10/111) 3. Quality (7/43) 4. Sustainability (5/39) 5. H&S (6/17)
Trust and no blame (why)	**Culture**	Mistrust and blame (who)
Helps projects flow	**Trust**	Difficult in practice
None/root cause analysis	**Blame**	Someone
Continuous learning/5 why's	**Problem solving**	Fire-fighting/5 who's
Timely problem solving	**Conflict resolution**	Disputes/litigation
Developing/Empowering	**People**	Control/Constrain/Hierarchy
Last Planner ® System (Pull)	**Planning**	Critical Path Method (Push)
Reliable	**Promises**	Unreliable
Natural	**Collaboration**	Forced
Everyone	**Coordination**	Management & Planners
Facilitator	**Project Manager**	Directive (Taylorism)
Command intent - Best for project	**Synchronized action** Alberts and Hayes, (2003)	Commanders intent - Best for PM
Decentralised	**Decision making**	Centralised
Relational (IFOA/Alliancing)	**Contracts**	Transactional
Flexible	**Specifications**	Strict (5/99)
Target Value Design & Choosing By Advantages	**Costings**	Quantity Surveying & Lowest bid
Lowest cost over lifecycle	**Total Cost of Ownership**	Typically looking at first cost
BIM - 7D	**Digital Project Delivery**	BIM - 3D
Shared/transparent	**Information**	Hoarded
Go and see	**Understanding**	Get it done
Means	**Management**	Results
Top down & bottom up	**Buy-in**	Top down
Intrinsic	**Motivation**	Extrinsic (8/45)
Uncertainty (Experiment)	**Commitment**	Certainty (Proof) (7/66)
Mentor/Sensi (All levels)	**Coaching**	Consultant (Top levels)

Serious Games	**Training**	Behaviorism
Less focus (10%)	**Tools**	More focus (90%)
Conception to abandonment	**Project Goals**	Max profit/min cost
Optimize the whole	**Productivity**	Optimize the piece
Collaborative	**Research**	Private
Internally	**Benchmarking**	Externally (others)
Process/Forward looking	**Metrics**	Results/Backward looking

CONCLUSIONS

There are many nuances and definitions relating to the theory of lean and LC. Defining exactly "what is LC?" is almost impossible and also may not be helpful. LC is a philosophy, therefore, it is open to interpretation depending on each discipline's viewpoint. Asking "how do you implement LC?" is another difficult question and similar to "how do you become happily married?" AEC projects and marriages are both usually one-off prototypes involving a unique set of people with different personalities. No single project or marriage will be the same. What works for one may not for another.

Rother (2010) cautioned against "implementing" lean as this implies certainty how it can be done. Rather, the path ahead is unclear. Successful AEC projects and marriages require teamwork and there will be challenges along the way. Simply implementing LC does not guarantee success. Project success is dependent on team success and collaborating together (Phelps, 2011).

Changing organisational culture and mind-sets is difficult. The brain naturally finds it hard to change our routines (Rother, 2010; Liker, 2014a). Transforming organisational culture is not a task that can be delegated to a single entity or an outside consultant. Leaders need to be developed at all levels in an organisation. Committing to self-development is another important initial step in any lean journey (Liker, 2014b). Engaging people at all levels helps to build a better, safer and happier environment for everyone to work in. To assure lean is sustained, the soft skills relating to the theory of LC such as leadership, empathy, motivation and collaboration will be required. The analysis detailed in Table 1 strongly suggests that current practice does not follow lean and LC theory as strongly as it should. A paradigm shift is required towards the current approach to planning, designing, delivering and operating AEC projects. While LC is far from commonplace, practitioners are focused on "wins" and "proof" rather than the management philosophy that is LC. Future education, training and increased research will show a different perspective – practice relating more strongly to theory.

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TOWARDS AN OPERATIONAL DEFINITION OF LEAN CONSTRUCTION ONSITE

Michelle Sjögren Leong[1], Steve Ward[2], and Lauri Koskela[3]

ABSTRACT

Through literature review and drawing from a combined professional experience of over 20 years of lean construction implementation, this paper investigates the key success factor for the automotive industry's uptake of lean production to see what the construction industry can derive from it.

The paper concludes that there exist a variety of definitions of lean, but no existing definition is yet satisfactory to describe lean construction in a rigorously testable method. This is a major obstacle to the successful deployment of lean construction especially when the industry does not have a standard benchmark of "what a lean site looks like". It recommends a small-scale replication of the International Motor Vehicle Programme (IMVP) led International Automotive Plant Study (IAPS) in construction. This will be in aid of developing an operational definition of lean construction, in line with Deming's understanding, in the form of a lean site assessment tool contributing to a Lean Index. A statistical study is also suggested to establish correlation between the degrees of lean application (Lean Index) and project performance.

KEYWORDS

Lean construction, waste, continuous improvement, operational definition, lean construction assessment

INTRODUCTION

This paper is based on UK discussions but with relevance to the global lean construction stage. There is a lack of clarity within the construction sector surrounding the concept of lean construction. Despite repeated calls to employ lean thinking from government via various reports, the majority of the industry has failed to respond. It may be the case that this is due to failure to properly articulate what lean construction means at a practical level.

Furthermore, whilst there are many isolated examples of success with lean construction, the correlation between the extent to which lean is applied and project success has not been properly established. Against this backdrop, the need to improve

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productivity has been identified as a significant opportunity within industry. If national targets are to be realised, it is imperative that efficiencies are found.

Rethinking Construction (Egan, 1998) first recommended the application of lean construction, in the UK, and set specific targets to include an annual reduction of 10% a year in time and cost and 20% reduction in defects. In his speech, on the 10th year anniversary of this report, Egan (2008) gave the construction industry a poor four out of 10 score for its effort. This demonstrates the UK industry's lack lustre drive towards continuous improvement. This can be seen as equivalent to the denial met by leading researchers of the International Motor Vehicle Program [4] (IMVP), when communicating Japan's competitiveness derived from superior performance to the Western counterparts (Holweg, 2007).

It was until irrevocable proof of under performance was produced and the obvious threat of further market encroachment by this superior performance that the voluntary adoption of lean production practices in Western car manufacturing was witnessed. This led to the revolutionary changes to work practices and attitudes.

Can we do the same for construction? This paper investigates the key success factor for the automotive industry's uptake of lean production to see what the construction industry can derive from it.

BACKGROUND

In order to start the investigation into what lean construction looks like, there is need to revisit lean journeys embarked upon by early adopters in order to give us an insight into what the construction industry's journey may look like and investigate any useful lessons to take onboard.

The Machine that Changed the World (Womack, Jones and Roos, 1990) revolutionised the way manufacturing industry operated and the accelerated adoption of lean by demonstrating the performance difference between lean production and mass production. The International Motor Vehicle Program (IMVP) was set up in the upshot of the second oil crisis in 1979 to investigate problems facing the world of motor vehicles. The "Futures of the Automobile" book, resulting from the IMVP research programme, was presented in 1985 alluding to the new ideas pioneered by the Japanese in gaining market share. This spurred the follow on Phase 2 research programme contributing to contents in the "*Machine*". The IMVP study set out to investigate the different way of working i.e. Toyota Production System (TPS) by the Japanese in order to compare it with the then current Western mass production techniques. The term lean production was coined by Krafcik, a research member of the IMVP team in his Masters thesis, and popularised by the "*Machine*". It was used in differentiating TPS practices to the "buffered" mass production way of working. (Krafcik, 1988a)

WHAT DOES LEAN MANUFACTURING LOOK LIKE?

The International Assembly Plant Study (IAPS) results presented in the "*Machine*" are from the sample of data gathered in 38 assembly plants in 13 countries between 1989-1990 (Krafcik, 1988b). The IAPS had a narrow but deep focus from the point of

[4] IMPV is the research programme behind The Machine that Changed the World book

the assembly plant but it collects data to enable comparison between “apples and apples”. They also collected data from correlating aspects including measures of plant operations, technology use, product complexity, manufacturing policies and human resource practices. In the second round of data collection from 88 plants and 20 companies between 1993 – 1994, further areas were included e.g. supplier relations, design factors and accounting systems. The IAPS focussed mainly on the productivity measure using labour hours required per car, but used other measures like defects per car to eliminate biases resulting from using one measure. (MacDuffie and Pil, 1995)

Results from the IAPS showed lean production to be twice as productive, to produce three times fewer defects and to achieve this using 40% less space with little inventories (Womack, Jones and Roos, 1990). And importantly, the second round results demonstrated great improvements. It showed European plants made circa 30% improvement in productivity, dropping their hours per vehicle from 37 to 25. European plants showed greatest improvement in quality, reducing defects per vehicle from 90 to 60 (MacDuffie and Pil, 1995).

Management Index

As interesting as the above section is, it still does not show or tell us how lean the production processes are. To do this, the IAPS adopted the 4M approach, namely Man, Machinery, Method and Material. Besides the assessed plant performance results using direct measures of productivity (hours per vehicle) and quality (defects/100 units) showing the existence of large performance spread throughout and within countries, the study also took into consideration that management policies (e.g. training, supportive non-adversarial environment) have huge impact on operations success. Multiple regression analysis showed that characteristics of management affect the relative “leanness” of the production management policies in place. It became obvious in the study that lean production management policies revolved around establishment of processes and safety nets in place to keep the system running while the traditional production management policies were designed to absorb problems cause by low skilled and poorly motivated workforce.

In view of this, to anticipate plant performance, a Management Index comprising four components[5] (teamwork, visual control, level of unscheduled absenteeism and percentage of floor space dedicated to repair facilities) was designed to capture the leanness of the plants’ production management policy. This proved to be an excellent predictor of plant performance, with productivity and quality improving as plants moved towards leaner operating policies. The relationship was found to be significant to productivity at a 99% level and at a 95% level for quality.

Results of this Management Index showed averages in Japan at 4.8 (very lean), US at 9.1 and Europe at 9.5 in a range of between 2 and 12. As importantly, the index demonstrated that the adoption of lean production method and management policies increased capability of high performance levels regardless of location or corporate parentage. (Krafcik, 1998a; Krafcik, 1988b)

[5] Each component scored against a number of criteria, e.g. visual control has 4 criteria including broadcasting of performance, degree of statistical process control usage, level of housekeeping, workplace organisation of stock area

WHAT CAN LEAN CONSTRUCTION LOOK LIKE?

As discussed in the introduction section, the automotive industry was in denial of its average performance. Now, the IAPS's robust methodology and dataset allowed for a like for like comparison. This may not have given new insights into the disparity in performance, but provided irrevocable evidence of it and invoked fear and survival in the lesser performers to react.

Unlike the automotive industry, most construction industries are national with local and regional labour market. However, similar drive for continuous improvement can be achieved if organisations with superior performance start capturing market shares within that market.

Arguably, the IAPS led to the successful adoption of lean by the aero industry. The Lean Aerospace Industry (LAI) was setup in 1993 in support of the industry lean programme. According to Wouter, et al. (2008), the aerospace industry is seen to be ten to fifteen years behind the automotive industry in adoption of lean and but that the industry is in grip of a revolution called lean. Their paper tested and supported the hypotheses that the aero industry is following the footsteps in pace with the automotive industry in transformation of the industry, albeit lagging behind in leanness due to the time lag in adoption. Like the IAPS, LAI has developed the Lean Enterprise Self-Assessment Tool (LESAT) to aid in supply chain management with the purpose of testing how lean a supply chain is.

As the construction industry is nowhere near the progression of the automotive or aerospace industry, in order to be able to depict what lean construction looks like, we may be wise to start small but nevertheless pick up on the need for assessing leanness as demonstrated by early adopters.

THE NEED FOR AN OPERATIONAL DEFINITION OF LEAN CONSTRUCTION

WHAT IS AN OPERATIONAL DEFINITION?

In Out of The Crisis, Deming (1986) states: "There is nothing more important for transaction in business than use of operational definitions". He goes on to say: "The only communicable meaning of any word, prescription, instruction, specification, measure, attribute, regulation, law, system, edict is the record of what happened on application of a specified operation or test." And: "Adjectives like good, reliable, uniform, round, tired, safe, unsafe, unemployed, have no communicable meaning until they are expressed in operational terms of sampling, test, and criterion".

An operational definition puts communicable meaning into a concept. It is certainly the case that lean thinking and lean construction are concepts and there is a great deal of confusion in industry regarding these concepts.

According to Deming, the formation of an operational definition is a three stage process where:

1. A specific test of a piece of material or an assembly
2. A criterion (or criteria) for judgment
3. Decision: yes or no, the object or the material (or concept) did or did not meet the criteria.

The Management Index used in the IAPS, described in a previous section, acts as an operational definition of lean production and produces a score that tells us how lean a plant is. It is 1) a test of four components with 2) a set of criteria within each components, where 3) a yes/no or scored decision can be made, deriving a single metric of leanness.

The Construction Predicament

Shah and Ward's (2007) paper on defining and developing measures of lean production provide some very salient points for consideration, even for construction. These are:

- They found that early Japanese books contributed to more explicit definitions of TPS and its fundamental components as opposed to the picking and choosing of relevant/perceived fundamental single components in latter literatures.
- The ambiguity of lean production demonstrated in varied descriptions and terminologies is partly due to the evolution of it over a long period as well as to the mixture of other approaches utilised.
- There are two perspectives when discussing lean, a philosophical guiding principle view (conceptual) and a practical set of practices view.
- They found only two studies specifically related to measuring lean production.

The points picked up in Shah and Ward's (2007) paper above reflects, in accordance, to the predicament of the construction industry. Even though not as progressed as the manufacturing industry, the application of lean thinking has been instrumental in transforming construction organisations, according to many papers of the International Group for Lean Construction (IGLC) and in the Lean Construction Journal from Lean Construction Institute (LCI). However the application of it to construction remains sporadic and fragmented with limited evidence of sustainability (Ward, 2015). Koskela (2000) is clear in his view that properly defined production theory is necessary to better enable success in the construction industry, and is critical of Womack, Jones and Roos (1990) five lean principles in that the terms they use are *"imprecise and unsystematic".*

Various parties within construction will have different explanations of what lean construction means. There are inconsistent definitions and little agreement among practitioners. This lack of an identifiable methodology and measure is one of the greater obstacles to lean construction adoption by contractors (Gao and Low, 2013; Stevens, 2014). The multitude of interpretations of lean construction contributes to making evaluating its application and its effectiveness difficult. Rybkowski, Abdelhamid and Forbes (2013) produced a graphic definition of lean from discussions at three occasions of IGLC and LCI meetings. This is due to their acknowledgment that there has been resistance from the lean construction community to commit to a collective definition of lean, even though lean construction has received increasing attention from academics and practitioners over the last two decades (Pekuri, Herrala and Haapasalo, 2012). According to Green (2011), lean construction, partnering and collaborative working rarely live up to the claims made on their behalf due to "definitional vagueness" inducing interpretation by stakeholders in line with individual needs.

This is very much in line with the first author's experience as a lean construction consultant for the past decade. There are huge differences between "lean-ness" amongst different practicing organisations and the level of lean even between projects of one organisation. Chase (1999), McGraw Hill Construction (2013) and Stevens (2014) highlight the fact that organisations and individuals claim to be lean when just implementing one or two elements and aspects of a lean tool or technique. As brilliant a tool as the Last Planner System (LPS) is, unfortunately, many in construction use LPS synonymously to lean construction. And even when claiming to be implementing LPS, one usually finds that it may only be an element of the system being applied e.g. look-ahead, weekly planning etc.

Rybkowski, Abdelhamid and Forbes (2013) detailed the various attempts to define lean over 20 years. Accordingly, they mentioned Oscar Wilde's quote that "to define is to limit". Rightly so, but there is need to highlight the objectives of defining lean. In this case it is to assess lean performance. If so, there may be need to, as suggested by Gao and Low (2014), to separate lean into "conceptual" and "implementation". There may not be need to define lean conceptually, but to have an operational definition of lean is a must if one is to test the application and evaluate its efficacy as strongly demonstrated by the automotive industry's progress in the field. According to Shewhart (1931) this means a clear state where "If you do so and so, then such and such will happen".

As suggested by Stevens (2014), the clarification and realignment of lean's definition and methodology and a meaningful way to measure the value of lean may motivate the construction industry to adopt lean. If how lean a site is can give indication to the expected performance of the project, the mainstream of the industry may be more likely to adopt the lean methodology and its tools and techniques. Stevens (2014) also pointed out that the middle management that controls and influences costs within construction are under time and cost pressure. They will not have the time to understand complex lean models. With no operational definition, heads of organisations cannot know if their sites are correctly applying lean or eliminating waste in line with the lean methodology. How can we induce industry uptake of lean construction if we do not know what the application of lean looks like? This is further corroborated by the McGraw Hill Construction (2013) market report, where potential lean practitioners stated that the lack of industry support and understanding of lean have a high degree of influence on their decision to adopt the lean approach.

A CLEAR BUSINESS CASE FOR THE ADOPTION OF LEAN CONSTRUCTION

Key drivers were identified on the uptake of lean construction in the report produced by McGraw Hill Construction (2013). These include client influence, greater profitability/costs reductions, competitiveness in the market, and programme reductions. There is also a distinct difference in drivers for existing lean practitioners and potential practitioners, with greater profitability/costs reductions being a commonality.

All **existing** lean practitioners agreed and ranked a) client influence, b) being leaders in the lean construction arena and c) the need to keep up/ahead with competition as top drivers with d) greater profitability/cost reduction and programme reduction to follow, whereas **potential** practitioners are highly influenced by greater profitability/cost reduction and greater productivity.

Understanding the different mind-set of the two groups and the different drivers will help in developing business cases and identifying enablers required to increase and accelerate the uptake of lean construction. In order to establish a clear business case with key drivers in mind, there will first and foremost be the need for an operational definition and defined methodology (components) as stated in the earlier section, very much like the IAPS Management Index.

According to McGraw Hill Construction (2013) only 14% of non-lean practising contractors find the industry inefficient/highly inefficient. This alludes to the argument that, like the automotive industry, there may first be the need to provide an assessment of the performance of the industry to show companies that they are not as efficient as they believe themselves to be, before the introduction of any "solutions".

Before a decision can be made to want to do something about a problem, there is first the need to acknowledge that the problem is there. This is the case for Volkswagen, when presented with an early notice of the results of the IAPS in Italy 1988. They were convinced that the benchmark figures were the evidence required to motivate and drive changes required within Volkswagen. Renault felt the same after presentation of the full results in Mexico 1989 and used the same methodology to benchmark their assembly plant efficiency. (Holweg, 2007)

Unlike the manufacturing industry, there are currently very few organisations in construction that can demonstrate consistent performance excellence. Hence the difficulty in addressing the point of what a lean project onsite looks like. But visible successes from the pockets of "excellent" applications by demonstration projects and existing practitioners can be found in construction for use to the same effect. These can be utilised to identify characteristics of lean performance and benchmarked against.

The round 2 results from the IAPS results showed that Japanese companies improved least in percentage improvements, as expected due to diminishing returns, but they led and continue to lead and triumph in all aspects of performance. For existing practitioners in construction, this indicates the importance and opportunity for capitalising on a "head start" and continuous improvement.

SUGGESTED APPLICATION OF LEAN INDEX IN CONSTRUCTION

The manufacturing industry, in their successful and sustained uptake of lean, demonstrated that a single metric, Management Index (assessment of management policies, e.g. training, supportive non-adversarial environment), showed strong correlation to operation performance (defects/100 vehicles and hrs/vehicle) and acted as a predictor of project performance. It is suggested that a similar approach be trialled encouraging further and more successful uptake of lean in construction.

LEAN SITE ASSESSMENT TOOL AND LEAN INDEX FOR CONSTRUCTION

A similar study as the IAPS but in construction is proposed here. This will require a site assessment tool, in line with Deming's understanding of operational definition and will, in turn, produce a lean index. A site assessment may be deemed most appropriate as it is farthest downstream, where the wastes caused by upstream processes surface and can be captured and ideally rectified at source in future projects. To address concerns that there is currently no comprehensive all round measure of lean performance on site (Forsberg and Saukkoriipi, 2007; Koskela, Bolviken and Rooke, 2013), the site assessment will need to take into consideration pre-construction processes, identifying root causes of poor/average processes and performance on site. The assessment tool should also be able to assess processes and management of processes regardless of circumstances i.e. quality of pre-construction handover to site, quality of clients, procurement, weather etc.

It is recommended that the site assessment be a tool that assesses the performance of construction projects against the 8 wastes associated with lean construction as recommended by Koskela (1992; 2004).This will be required to differentiate the assessment from assessments based on other schools of approaches (Shah and Ward, 2007; Koskenvesa and Koskela, 2011).It needs to evaluate performance against identified functional areas of how a site/project is managed that directly relate to improving the ratio of value to waste. Within the identified areas, there can be criteria of existing, good to great, practices derived from pockets of excellence within the industry. Performance evidence needs to be sought and the meeting of criteria can be assessed, scored and tallied contributing to a lean index. A maturity matrix approach is recommended, to gauge progression from average to excellent against each area, as a lean assessment should not only evaluate performance (Smyth, 2010) but also provide a gap analysis on performance to include recommendations for continuous improvement.

With a robust lean site assessment tool and a strong suite of data collected behind the lean index, a business case may be made for the uptake of lean by industry for both potential and existing lean construction practitioners. The results of the site assessments and lean index can potentially have great benefits. These include:

- Indication of current project performance on individual sites with a route map for specific and immediate improvements
- Initial benchmark of organisational performance based on projects assessed with a route map for specific organisational improvements along the whole value stream
- Identification of management skills gaps
- Rigorous analysis and credible statements of current performance and improvement plans for increased chance of winning work
- Ability to influence client procurement giving advantage to a supply chain that strives for performance improvement with the ability to provide concrete evidence of lean application
- Ability to assist clients in enabling them in better risk management of their supply chain

A statistical study will need to be conducted to investigate correlation between the lean index i.e. degree of application of lean, and project performance.

CONCLUSIONS

Following in the evolution of the lean production journey, there is a need to test the leanness of construction projects onsite to show current performance benchmarked against potential "excellence", in this case, derived from the existing pockets of excellence. The results may jolt our own industry to an accelerated uptake of lean construction and a change in attitude like the IAPS results did to the automotive industry.

In order to do the above, we must first have a robust and defined methodology and operational measures of what lean construction is, i.e. a standard measure of lean application (leanness).

It is recommended that a similar study to the IAPS be conducted in construction, producing a Lean Index to demonstrate the leanness of projects and organisations. This single metric can contribute to increased competitiveness in a wider industry context and also serve as a continuous improvement benchmark in the individual organisations' own improvement journey.

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A CASE STUDY ON DESIGN SCIENCE RESEARCH AS A METHODOLOGY FOR DEVELOPING TOOLS TO SUPPORT LEAN CONSTRUCTION EFFORTS

James P. Smith[1]

ABSTRACT

Effective application of lean theory in construction generally requires tools and/or processes to facilitate implementation. Last Planner System®, A 3 problem solving, plus/delta and pull scheduling sessions are a few examples. These kinds of tools assist construction participants in making the shift from abstract theories to project application. As innovation in this area is constantly occurring in the lean community, methodologies for developing new tools warrant consideration and testing.

Design Science Research (DSR) is a methodology that was strongly recommended by facilitators during the 2012 International Group for Lean Construction Summer School program in San Diego, CA. This paper uses a project that attempted to develop a trust-building tool as a case study to analyze the effectiveness of DSR as a methodology. The results of the project show support for the continued application of DSR methodology in the development of tools and processes supporting lean construction efforts. It was determined that the flexibility and iterative evaluation loop inherent to DSR were effective at providing a framework for the tool created in the case study project. However, the comparative need for time associated with iteration may limit interested researchers' ability to apply DSR to future projects.

KEYWORDS

Lean construction, action learning, process, design science research, constructive research.

INTRODUCTION

The continued dissemination of lean theory in the construction industry isheavily dependent on the ability of potential adopters to overcome implementation barriers and effectively apply lean principles to their projects and teams. According to Alarcon, et al. (2005), a variety of implementation barriers exist such as lack of training, lack of self-criticism and weak communication among participants, among others. In order to overcome these barriers, adopters need tools, techniques and/or

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processes to help bridge the gap between an understanding of the theory itself, and what the application of that theory actually looks like on a job site.

There have been many tools, techniques and processes (hereafter referred to collectively as tools) developed that aim to assist participants in making the transition from theory to application. Some tools, such as Last Planner System®, A3 problem solving, plus/delta and pull scheduling sessions are regular components of many project teams' efforts. Other tools like the airplane game, Parade of Trades (a.k.a., the dice game) and the Red Bead Experiment are geared towards introducing and teaching lean theory to those considering implementation. Many lean construction pioneers first "ah-ha" moments came as a result of tools such as these.

As innovation in this area is constantly occurring in the lean community, with new tools emerging regularly, methodologies supporting tool development warrant consideration and testing. This paper uses a research project that attempted to develop a trust-building tool as a case study to analyze the effectiveness of one particular methodology – Design Science Research (DSR). The use of DSR as a research methodology was strongly encouraged by the facilitators, Dr. Lauri Koskela and Dr. Carlos Formoso, during the 2012 International Group for Lean Construction Summer School program in San Diego, CA.Similar to Rocha, et al. (2012), this paper provides a review of DSR methodology followed by details about how DSR was implemented in a particular case study including feedback regarding the strengths and weaknesses of this methodology for the continued development and innovation of tools to support lean construction efforts.

DESIGN SCIENCE RESEARCH

Design Science Research methodology, also called Constructive Research in accounting literature (Lukka, 2003), has received attention and support in fields such as business administration, information systems and technology, medicine, and engineering research (Kasanen and Lukka, 1993; Lukka, 2003; Van Aken, 2004; Hevner, et al., 2004). This wide-spread adoption is likely due to DSR's apparent ability to align the academic side of a given field with its industry counterpart.

It has been suggested that DSR is capable of assisting with the relevance or utilization problem that exists in many academic fields (e.g.Van Aken, 2004; Kaplan and Johnson, 1987). In management research, this issue has been called the "rigor-relevance dilemma" (Whyte, 1991). Van Aken explains that this dilemma occurs when "theory is either scientifically proven, but then too reductionistic and hence too broad or too trivial to be of much practical relevance, or relevant to practice, but then lacking sufficient rigorous justification" (Van Aken, 2004, pp. 221). The goal of DSR is to "produce innovative construction, intended to solve problems faced by the real world and, by that means, to make a contribution to the theory of the discipline in which it is applied" (Lukka, 2003, pp. 1).

Generally speaking, DSR appears to be a good fit for research in lean construction because of the field's "applied" nature. Researchers have suggested that industry players, namely architects, engineers and urban planners, deal with problems that can be appropriately resolved using DSR (Van Aken, 2004). By selecting a methodology that supports real-world application, researchers might be able to avoid what Meredith, et al. (1989) decried as research that is high in "academic prestige" at the expense of relevancy to real-life problems.

DSR GUIDELINES

The guidelines for DSR, as published by Hevner, et al. (2004), are provided in Table 1 to create the framework for the discussion regarding the differences between DSR and more "traditional" research methods.

Table 1: Design Science Research Guidelines (Hevner, et al., 2004)

	Guideline	Description
1	Design as an artifact	DSR must produce a viable artifact in the form of a construct, a model, a method, or an instantiation.
2	Problem relevance	The objective of DSR is to develop technology-based solutions to important and relevant business problems.
3	Design evaluation	The utility, quality and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.
4	Research contributions	Effective DSR must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.
5	Research rigor	DSR relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.
6	Design as a research process	The search for an effective artefact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
7	Communication of research	DSR must be presented effectively both to technology-oriented as well as management-oriented audiences.

A Model for DSR

DSR's model shows similarities to the general structure of Van Strien's (1997) "regulative cycle". Van Strien's cycle is made up of five main steps:

1. Identification of a problem
2. Diagnosis of the problem situation
3. Creation of a plan of action
4. Intervention aimed at affecting change
5. Evaluation of the new situation

The various components of this cycle are included in a model for DSR implementation, see Figure 1, created by Vaishnavi and Kuechler (2007). In addition to Van Strien's steps, the model includes representations of the knowledge transfer or flow occurring between the steps and also the outputs associated with each of the steps.

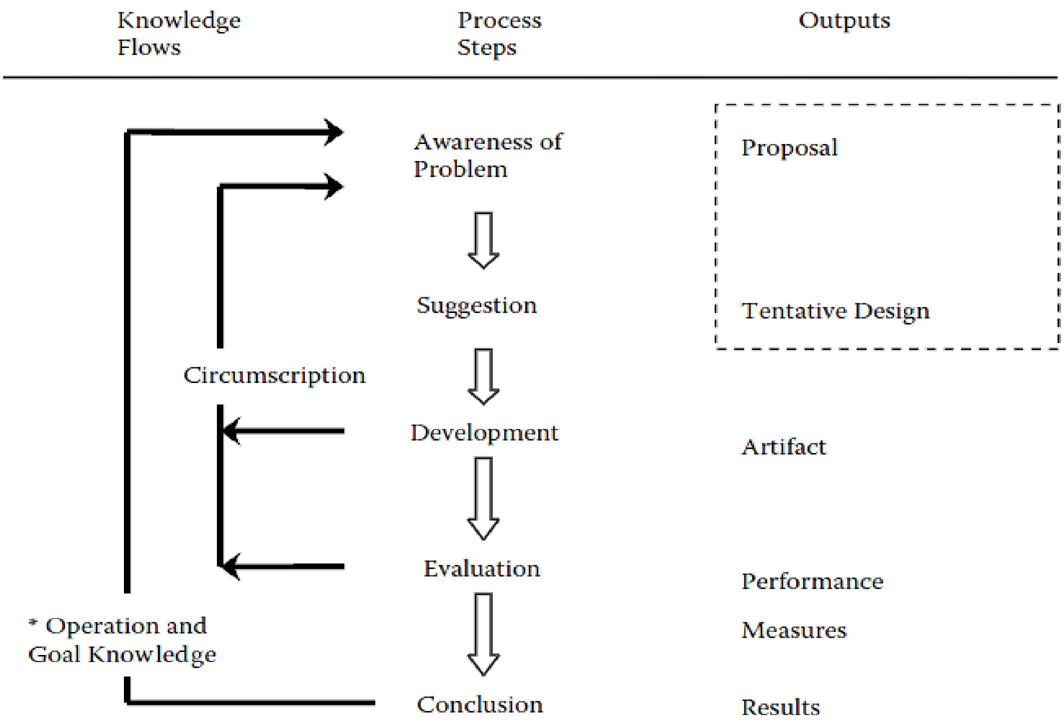

Figure 1: A Model for Design Science Research (Vaishnavi and Kuechler, 2007)

One of the key features of DSR is the iterative nature it requires. The development and evaluation stages provide feedback for an improved awareness of the problem and more effective suggestions for its solution until satisfactory results are achieved. This model is similar to those proposed by various quality management theorists. The Deming Cycle consists of four similarly simple steps: Plan-Do-Check-Act (PDCA) (Deming, 2000). Each of these approaches to improvement could be considered forms of action learning.

Descriptive vs. Prescriptive Research

Early work and conceptual support for DSR were provided by Simon's (1996) seminal book, The Sciences of the Artificial. In his work, Simon describes a difference between naturally occurring and artificially occurring phenomenon. March and Smith (1995) point out that scientists can contribute to not only the study of these artificial phenomena, but also the creation of them. This dual capacity allows for scientific involvement in both sides, as opposed to natural phenomena which by definition occur without intervention and can merely be described or explained.

According to the work of March and Smith, natural science, or more traditional research in the "hard sciences," is generally aimed at understanding and explaining reality, and can thus be classified as descriptive research. Alternatively, DSR attempts to *create* things that serve specific purposes or needs (Denning, 1997). Products from design science are tested against the value or utility they bring, generally based on the value-determining question – "does it work?" (March and Smith, 1995, pp. 253) This type of work is classified as prescriptive research. In other words, where "natural sciences are descriptive and explanatory in intent, design science offers prescriptions and creates artifacts that embody those prescriptions"

(March and Smith, 1995, pp. 254). Hevner, et al. (2004) described the difference and association between the two as follows:

"The goal of [natural] science research is truth. The goal of design science research is utility… Our position is that truth and utility are inseparable. Truth informs design and utility informs theory." (Hevner, et al., 2004, pp. 80)

Table 2, adapted from Van Aken (2004), describes the main differences between the two approaches.

Table 2: Main Differences between Descriptive and Prescriptive Research (Van Aken, 2004)

Characteristic	Descriptive Research	Prescriptive Research
Dominant paradigm	Explanatory sciences	Design sciences
Focus	Problem focused	Solution focused
Perspective	Observer	Player
Logic	Hindsight	Intervention-outcome
Typical research question	Explanation	Alternative solutions for a class of problems
Typical research product	Causal model; quantitative law	Tested and grounded technological rule
Nature of research product	Algorithm	Heuristic (hands-on)
Justification	Proof	Saturated evidence

For additional analysis and exploration on the differences between descriptive and prescriptive research, please refer to Holmström, Ketokivi and Hameri(2009).

The "applied" nature inherent to lean construction research can be viewed as being highly prescriptive in nature. We use innovative tools to create or suggest an intervention and affect the resultant outcome. The focus is on a solution that is created, tested, evaluated and iterated in an effort to achieve a desired outcome. The success of the tool is measured by its ability to achieve the prescribed goal. It is heuristic in nature in that it provides an alternative set of possible solutions for a problem and is then evaluated on a trial and error basis.

POTENTIAL BENEFITS AND RISKS

Testing tools in the context of their anticipated application introduces additional variables to the research design that may be difficult to manage. Similar to some clinical research, the heuristic approach can make it difficult, if not impossible, to draw conclusions about causation. However, the ability to test tools in the context of their designed use also provides validity that can arguably be lacking in true laboratory experiments. Van Aken (2004) suggests that despite its weaknesses, sufficient supporting evidence can be obtained using this method, in addition to improved assurances of effectiveness in the intended context of application. In this way, the solution can be tested without being overly reduced by the need for quantification, possibly giving more holistic results. The starting point is what

Pawson and Tilly (1997) called the basic realist formula: *mechanism* + *context* = *outcome*.

Table 3 summarizes known potential benefits and risks of constructive research, or DSR, as listed in Lukka's (2003) analysis of the methodology.

Table 3: Potential Benefits and Risks of Design Science Research (Lukka, 2003)

Benefits	Risks
Access to new interesting research sites	High relevance of study results can be perceived by the participants as being "too delicate" to be published (Lukka, 2003, p. 13)
Participants get critical analysis of relevant problems	Cannot maintain the commitment of the target organization or participant
Gap between research and practice is narrowed	Participants fear losing control of business secrets
Practitioner has interest in providing honest and relevant data	Anticipating and managing side-effects or confounding variable (March and Smith, 1995)
Demands thorough prior knowledge in order to be implemented	Neutrality of the researcher
	May be viewed by journal editors and peer reviewers as an un-established methodology

As with any risks, these potential risks need to be analyzed in the context of the specific project and managed to avoid any negative impacts. Similarly, these potential benefits should be highlighted to maximize their positive impacts.

THE CASE STUDY – DEVELOPMENT OF A TRUST-BUILDING TOOL

As previously mentioned, this paper is a case study on a project that used DSR in order to develop a trust-building tool for the construction industry (Smith, et al., 2014). The remainder of this paper provides detailed results, analysis and discussion regarding how DSR was implemented and its strengths and weaknessesin this particular case study.

CONTEXT

The case study project was conducted by multiple researchers over the course of approximately 2 years as part of a graduate degree. The goal of the project was to create a tool that assisted users in their efforts to build interpersonal trust with construction project participants. Trust was viewed as a key attribute necessary for the collaboration inherent to lean project delivery. The project used a mixed methods design within the phased framework suggested by DSR (see Figure 1). Table 4 describes the overall project approach including specific embedded methodologies used by the researchers. Some details regarding implementation of each specific methodology within the DSR framework are included in Smith, et al. (2014) and others are forthcoming in pending publications.

Table 4: Case Study Schedule of Events and Methodologies

Project Phase		Description	Approximate Duration
I		Awareness of the Problem	1 year
	A	Semi-structured Interviews	1 month
	B	Project/Site Observations	1 month
	C	Iterated Questionnaire	10 months
II		Suggestion of a Solution	Milestone
III		Development	9 months
	D	α-Testing: internal analysis	3 months
	E	β-Testing Stage I: first –run study with student participants	3 months
	F	β-Testing Stage II: case study application with industry participants	3 months
IV		Evaluation – conducted following each stage of development phase	7 months
V		Conclusion	Milestone

Using the same designations included in Table 4, Figure 2 graphically describes the sequencing adopted for various components of the project.

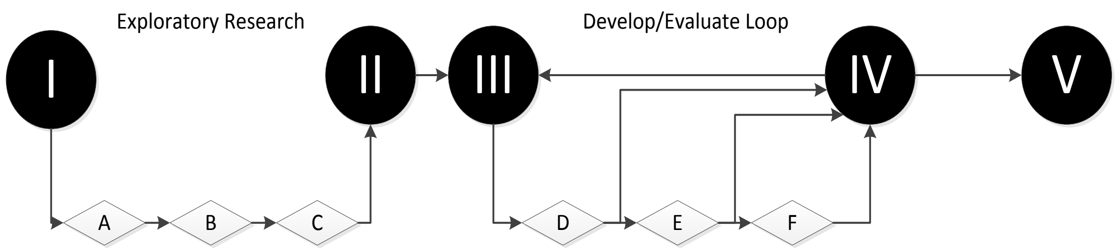

Figure 2: Sequencing of Events and Methodologies

As described in Table 4 and Figure 2, the case study's research teamexplored the topic of trust in construction using semi-structured interviews and observations to inform an iterative questionnaire. These exploratory methods were used to confirm relevance of the proposed research topic to industry participants. This process also allowed for the team to narrow down potential research directions and research questions. The interviews were comprised mainly of open-ended questions designed to avoid limiting participants' responses. The combination of these methods effectively provided an awareness of a general problem that exists in the construction industry relating to low levels of interpersonal trust between key project personnel.

The research team in the case study then suggested a possible solution for the low level of trust – in this case a tool to assist project participants in their efforts to build trust. This suggestion was immediately followed by three levels of development, the evaluation, assessment and feedback collected at each level informing the next iteration of the trust-building tool. After the initial development stage (α-Testing) which consisted of internal analysis and basic pilot testing, an updated version of the tool was tested in a quasi-experimental design using students as subjects, followed by a series of case studies using industry practitioners as subjects. Details on the artifact/tool created in this case study can be found in Smith, et al. (2014). This approach provided support for some of the known risks associated with DSR while at the same time capitalizing on the known benefits (see Table 3).

DSR STRENGTHS

To assess the strengths of DSR, the final results of the case study project must be analyzed. Success, in this instance, is truly determined by whether or not the developed tool accomplishes what it was designed for (March and Smith, 1995). However, in an effort to provide an exhaustive review of the overall methodology, ancillary results from the various phases of the project will also be analyzed.

Complementary Phasing

There were two major work packages in the case study project. The first package consisted of Phases I and II which were primarily descriptive in nature. Results from the first package created the starting point for the second package consisting of Phases III and IV which were primarily prescriptive in nature. Many research projects consist of only one of these two work packages. The case study project team felt that in comparison to the many projects consisting of only one of these two, DSR's combination of the complementary approaches provided for improved development of useful tools by ensuring that the tools provided solutions to real problems.

This complementary phasing in DSR also supports a holistic approach to critical thinking and problem solving. One researcher recommended this model as appropriate for any graduate student that has interest in a specific topic but has yet to develop a specific research question. It was suggested that a focus on the identification of an actual real-world problem during the "awareness of the problem" phase, although time consuming, was very valuable in the overall creation of an effective tool.

Flexibility

Most data collection methodologies can fit within the DSR framework. This allows the researcher to select the most appropriate data collection techniques (e.g., simulation, observation, case study, surveys, etc.) for the various phases of the project. This flexibility allows for a wide range of data types and data sets which also can serve to strengthen the final results.

Additionally, an emphasis on becoming aware of the problem during Phase I can prevent problem solvers from becoming mistakenly focused on a problem or a question that is of little interest or value to the relevant industry. Maintaining flexibility during the problem definition supports more useful solutions in the end.

Respondent Engagement

Early engagement by respondents on the exploratory end of the project seemed to create increased interest and involvement on the development end. It also supported the idea that both the problem and the solution would be relevant to those in industry. This increased interest greatly assisted in the repetitive testing and data collection portions of Phase III/IV. These observations supported a number of Lukka's (2003) proclaimed benefits from Table 3.

Useful Tool Creation through Iteration

As mentioned, a successful resultant tool is the best indicator of how effective DSR methodology is. The results from Phase III/IV/V of the case study, both quantitative and qualitative, showed support for the project's hypothesis that interpersonal trust could be actively managed by using a tool like the one that was created. The effectiveness of the tool improved with each iteration of the develop/evaluate loop critical to DSR, and utilization of multiple groups and multiple methodologies allowed for triangulating support for the hypothesis. In the end, the final version of the tool successfully helped three different industry participants build trust with construction project counterparts.

Theory Development

Finally, the controlled but flexible DSR methodology allowed for concurrent theory development during the course of the project. In this case study, the theoretical development was a new model for trust-building. The model benefited from DSR iterations which allowed for specific components to be added or removed as dictated by the latest results.

DSR Weaknesses

Project Duration

The completion of a DSR project as modelled by the case study can be time consuming. Many practitioners and/or researchers (graduate students and otherwise) are not able to devote as much time to the iterative develop/evaluate loop as may be needed. Similarly, excessive requests on respondent time, particularly industry participants, may lead to a lack of commitment as described by Lukka (2003).

Confounding Variables

The project team found that testing a tool in the context of its anticipated application created potential confounding variables. The lack of experimental control consistent with construction jobsites and everyday interpersonal interactions makes it difficult to remove unanticipated variables that could potentially affect study results. The inability to draw specific conclusions is a weakness that was also identified by previous researchers.

CONCLUSIONS

The results of the project show support for the continued application of DSR methodology in the development of tools, techniques and processes supporting lean construction efforts. It was determined that the complementary phasing, flexibility and iterative evaluation loop inherent to DSR were effective at providing a framework for tool creation in the case study project. However, the comparative need for adequate time to allow for iteration may limit interested researchers' ability to apply DSR to future projects. Also the potential for confounding variables resulting from testing tools in their anticipated context necessitates preventative management (e.g., mixed methods data triangulation) on the part of the interested researcher.

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WHERE RHETORIC AND LEAN MEET

Lauri Koskela[1]

ABSTRACT

This paper aims at an initial analysis and explanation of lean through the lens of the discipline of rhetoric. First, the ancient origin, central ideas, subsequent history and current interpretations of rhetoric are outlined. Then, the overall meeting points of rhetoric and lean are discussed. At the outset, it is contended that certain arguments that can be used as a justification in rhetoric seem fertile for understanding the difference between lean and conventional management. Then, persuasion towards compliance in production is discussed. The field of visual management is argued to have an implicit foundation in rhetoric. The existence of a common ground of values, facts and presumptions between the speaker and the audience is emphasized in rhetoric; it is contended that lean construction in many ways endeavours to create such a common ground among the project participants. Regarding deliberation, the rhetorical dimensions in the methods of A3 and Choosing by Advantages are discussed. Further, Target Value Design is identified as based, for their part, on rhetorical ideas. In conclusion, it is contended that many aspects of lean, which as such may seem odd and perhaps peripheral, can be explained through the classical and modern understandings of rhetoric.

KEYWORDS

Lean construction, lean production, rhetoric.

INTRODUCTION

What does happen between the representation of the building (drawings) and the process (plan), on the one hand, and the completed building, on the other hand? Obviously, there will be the physical production process, but for achieving a perfect outcome, there needs to be production personnel who *adhere* to the product and process representations. How is this adherence realized?

Actually, the discipline for achieving adherence, rhetoric, is one of the oldest. However, it fell out fashion already in the 19th century, although there is now a movement towards its revival. The question arises whether techniques and principles of rhetoric are already used in lean construction, and if not, could they be used more effectively. A secondary question is whether rhetoric is used in conventional construction management.

The paper is structured as follows. First, the ancient origin, central ideas, subsequent history and current interpretations of rhetoric are outlined. Then, the

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overall meeting points of rhetoric and lean are discussed, focusing on fundamental arguments of production management, on compliance to drawings, standards, plans and instruction, on reinforcing common values and widening the informational common ground, on deliberating, promoting and assessing alternative courses of action, and on inventing requirements, issues and ideas. Conclusions are presented at the end of the paper.

RHETORIC

ORIGIN

The emergence of rhetoric was connected to the need of citizens to speak for themselves and persuade in courts of law in Greece of early Antiquity. A body of knowledge on how to speak publicly was formed. The great scientist of the time, Plato, had a negative view on rhetoric, but his pupil Aristotle systematized it in a treatise. The rhetorical tradition continued to the Roman time, during which several guidebooks on rhetoric were prepared. Cicero and Quintilian are among the more well-known experts and authors of rhetoric in Rome. Rhetoric was a central ingredient of education of sons of noble families, and this role of rhetoric continued until the modern time. Already in Antiquity, rhetoric showed the tendency of migrating, besides writing, to artistic and design fields, such as painting, music, sculpture and architecture (Ballard and Koskela, 2013; Koskela and Ballard, 2013).

CENTRAL IDEAS

Already the Greek and Roman handbooks and treatises on rhetoric contained a wealth of descriptive, explanatory and prescriptive knowledge on oratory. Among the most well known were the stages of preparing and delivering a speech:

- *Inventio* (invention) concerns finding and discovering the topics of a speech; also determining the nature of the case, selecting the intention and analyzing the audience.
- *Dispositio*(arrangement) is about organizing the topics into a speech; parts into a whole.
- *Elocutio* (style) refers to different rhetorical methods and devices by means of which the topics were to be delivered.
- *Memoria* (memory) as a stage is related to the fact that in Antiquity, speeches were mostly delivered from memory.
- *Actio* (delivery) refers to the use of gestures, face expression, voice and similar during the delivery of the speech.

As an example of the early achievements of rhetoric, the suggestion for arranging a legal case by Corax (5th century BC) can be presented. His scheme, falling into guidelines for *dispositio*, contained the following: (1) Introduction, (2) Statement of the Case, (3) Argument Summary, (4) Proof of the Case, (5) Conclusion. Still today, the U.S. Supreme Court requires essentially the same structure to be used (Frost, 2005).

Besides methods and techniques, classical rhetoric embraced a powerful conceptualization of the rhetorical situation, consisting of the orator, the vehicle of persuasion (typically speech), and the audience. This allows for useful and interesting analyses on situational compatibility of these three different elements. The related idea that a presentation should be adjusted to the intended audience is of course widely known. One more widely known piece of rhetorical knowledge concerns "common ground", that is, the shared values, facts and presumptions between the orator and the audience[2].

SUBSEQUENT HISTORY

Since Aristotle's time, geometry had been seen to provide a model of necessary reasoning and rhetoric, in turn, a model for plausible reasoning. Descartes achieved a radical re-interpretation where only necessary reasoning was accepted as valid. Rhetoric was narrow down and relegated, especially by Ramus (1515 – 1572), into mere elocution, ornamentation of speech (Sellberg, 2014).

Whilst Renaissance (from the 14th to the 17th century) was characterized by the reinvention of the scholarship of Antiquity, Enlightenment (from late 17th to 18th century) represented a counter-move, towards a new understanding, especially of natural science, and a rejection of the authority of classical authors. Indeed, Enlightenment started the so-called Modern period, one characteristic of which is the expectation that useful knowledge is something recently created. Rhetoric, having advanced already in Antiquity, did not fare well in this atmosphere. Of course, the narrowed-down definition of rhetoric influenced in the same direction. A further factor was that the achievements of rhetoric had the tendency of being subsumed by other emerging disciplines, with the outcome of hollowing out of the original discipline. Thus rhetoric encountered a slow decline; for example, the University of Helsinki lost its Chair of Rhetoric in 1852.

CURRENT INTERPRETATIONS AND RE-INVENTIONS (OR ALMOST)

In the beginning of the 20th century, the void left by the neglected discipline of rhetoric started to be filled with new entrants, notably communication studies or communication theory. However, these fields lacked the clear focus, unity and historical continuity enjoyed by rhetoric in its heyday.

In the latter part of the 20th century, there have been initiatives to revive classical rhetoric, led notably by Perelman and Toulmin (2001). Among the newest literature, there are even examples where the historical continuity and the width of application of rhetoric is fully recognized. For example Hellspong (2013) presents rhetorical ideas and guidelines from Antiquity, at equal footing, alongside scholarly views from recent decades.

On the other hand, lacking knowledge of classical rhetoric has led to a situation where time-honored concepts and principles are re-invented (or almost), especially in social and managerial sciences. An intriguing example is provided by the concept of boundary objects, which was forwarded by Star and Griesemer (1989) alongside methods standardization as essential for cooperation between actors with different viewpoints. After that, the concept of boundary object has received constantly

[2]Noteworthily, the term "common ground" is of Anglo-Saxon origin. It seems to have been a legal term, a synonym of "common land" or "commons". Thus, the dictionary of Ash (1775) defines "commoner" as "one that has a right to the common grounds". However, this term has been used in a metaphorical sense from early on. For example, Burnet (1697) writes: "…taking that common ground, which both Moses and all Antiquity presents to us…".

increasing attention in social sciences, whereas the interest towards methods standardization has been negligible[3].Actually, both concepts can be closely connected to rhetoric, especially to the idea of common ground[4].

In turn, policy analysis and planning encountered an "argumentative turn" in the 1980's (Fisher and Forester, 1993), but seemingly without any idea that in Antiquity, one of the functions of rhetoric was precisely to help frame speaking about courses of action in public affairs.

A further example is provided by the language/action perspective, originated by the philosopher Austin (1962). He promotes, as a novelty, the concept of performative utterances, through which the speaker is doing something rather than merely saying something, without recognizing that the whole point of rhetoric is to do things with words: to persuade and secure adherence.

WHERE DO RHETORIC AND LEAN MEET?

From the multitude of aspects where rhetoric and lean meet, the following are addressed in this presentation:

- Fundamental arguments of production management
- Compliance to drawings, standards, plans and instruction.
- Reinforcing common values, widening the informational common ground
- Deliberating, promoting and assessing alternative courses of action
- Inventing requirements, issues and ideas.

These are discussed in more detail in the following, also making reference to the state of affairs in conventional production management.

FUNDAMENTAL ARGUMENTS IN PRODUCTION MANAGEMENT

Among the seventeen types of arguments that can be used for rhetorical purposes, listed by Perelman and Olbrechts-Tyteca (1969), at least the following have relevance for production management:

- Argument of means and ends
- Argument of best means
- Argument of waste

[3]That the idea of boundary objects so directly resonates with the premises of Actor Network Theory, while the connection of method standardization to it is less clear, may explain this discriminating treatment.

[4] Star and Griesemer (1989) characterize methods standardization as follows: "First, and perhaps most important, methods standardization allowed both biologist and collectors to find a common ground in clear, precise, manual tasks." Regarding boundary objects, the following quote is revealing: "At the core and beginning of his work, then, he placed a common goal and understanding, with boundaries from several different worlds which coincide. These coincident boundaries, around a loosely-structured boundary object, provide an anchor for more widely-ranging, riskier claims." Although the authors do not use the term "common ground", the description fits with it very well. The same applies to a specific type of boundary objects, standardized forms: "These are boundary objects devised as methods of common communication across dispersed work groups."

- Argument of unlimited development

As it is well known, from these, lean production is based on the arguments of waste and unlimited development. Conventional production management may be mostly be based the argument of means and ends, but also on the argument of best means (the idea of optimal production)[5]. The crucial thing is that the selection of the fundamental argument for shaping production management has far-reaching consequences: if the arguments of waste and unlimited development are relied on, practical efforts will focus on the determination of waste and its elimination through continuous improvement. In turn, if the arguments of means and ends, along with the best means, is relied on, practical efforts will focus on creating a feasible, and if possible, optimal plan[6]. In fact, this gives a high-level explanation for the difference of lean and conventional production management.

COMPLIANCE

In lean construction, one of the major means for achieving compliance is visual management. Galsworth (1997) defines a visual workplace, resulting from visual management, as follows: "A visual workplace is a work environment that is self-explaining, self-ordering, self-regulating, and self-improving - where what is supposed to happen does happen, on time, every time, day and night." For the person encountering visual management for the first time, there are three surprising features: (1) the wide use of visual means in communication, (2) the tendency to make visual tools understandable for everybody, rather than just the team in question, (3) the pursuit of presenting all relevant information immediately at the place of work.

Actually, there is a rhetorical explanation for all of these three features. First, as commented by Perelman and Olbrechts-Tyteca (1969) as well as van Eck (2007), in classical rhetoric, verbal persuasion was fluidly connected to visual persuasion, and even further, visual arts like painting, sculpture and architecture were shaped based on rhetorical theory. Thus, visual persuasion – and this is what visual management ultimately is - can be seen as a generalization of rhetoric.

Second, although the consideration of the specific audience when preparing a speech is perhaps one of the most well-known principles of classical rhetoric, Perelman and Olbrechts-Tyteca (1969) contend that in rhetoric, the universal audience should also be taken into consideration, besides the specific audience. It seems that visual management seems to completely aligned with this recommendation.

Third, Perelman and Olbrechts-Tyteca (1969) view presence as a major rhetorical device. Indeed, it seems that in visual management, presence is directly and widely used, leading to the systematic posting of relevant information at the work face.

In comparison, the principles used for compliance in conventional production management are not very prominent. However, it is safe to say that these principles of visuality, universal audience and presence are hardly used. Necessary information and

[5]The fate of Critical Path Network (CPM) is illuminating. Whilst in early treatments (Moder and Phillips, 1964), the nature of CPM as optimization is emphasized, recent textbooks, like (Sears, Clough andSears, 2008) characterize CPM as a predictive model, useful for the management of construction projects. Thus, there has been a withdrawal from the argument of best means to the argument of means and ends.

[6]It can be argued that there is also a presumption of the nearly perfect realization of the optimal plan and thus absence of waste.

knowledge is expected to exist in textual form or to be tacitly held by the operatives, technical language understood in the context is seen sufficient, and external means (databases, shelves) for storing the information/knowledge are considered adequate.

COMMON GROUND OF VALUES, FACTS AND PRESUMPTIONS

The starting point of persuasion in classical rhetoric is that there is a common ground between the orator and the audience, consisting of common values, mutually known facts, and commonly held presumptions. Indeed, the orator is advised of the importance of communion with the audience (Perelman and Olbrechts-Tyteca,1969).

Lean construction is extensively using methods for reinforcing common values, providing facts for everybody and thus enlarging the common ground. The above-mentioned methods of visual management seem often to be geared towards this. Especially, the practice of the Big Room seems to be a paramount means towards creating a broad and solid common ground. Also, the phase planning and the weekly planning sessions of the Last Planner System of production control (Ballard, 2000) seem to function to the same effect.

Instead, conventional production management, structured as a command and control hierarchy, seems not geared of widening and strengthening the common ground.

DELIBERATION

In matters related to design and planning, there needs to be “the customer’s voice” but actually there are a multitude of voices, and each wants to persuade in the discussion on what should be done. In this discussion, the importance of using the whole palette of the rhetorical arsenal accentuates, for example all the categories of influencing: *logos*, *ethos* and *pathos*. It is also opportune to quote Perelman and Olbrechts-Tyteca(1969) regarding one easily overlooked issue, order[7]:

“For order is also one of the conditions that determine amplitude; it is the selection of matters that will be taken into consideration by the participants. Attention to order ensures not only that individual reflection shall not stray into wrong paths, but also – and this is the most interesting point – that fruitful paths shall not be prematurely abandoned. In other words, order ensures that particular premises are given sufficient presence for them to serve as starting points for reflection.”

In the following, two methods for deliberation used in Lean Construction are analyzed: the method of A3 and Choosing by Advantages.

In his book “The Toyota Way”, Liker (2005) presents the "A3 Report“ as an example of an efficient communication tool (under Principle 13: Make decisions slowly by consensus, thoroughly consider all options; implement decisions rapidly). The question is about an A3-sized structured document for problem solving, proposing action or project status reporting. The A3 method has rapidly diffused and proved effective. What is the explanation?

From a rhetorical viewpoint, the question is about standardized order: A3 provides a standardized method and documentation for problem solving, proposals and review

[7] It is worth noting that Set Based Design endeavours to allow more time for the development and comparison of alternative solutions, in full alignment with the quoted statement by Perelman: “fruitful paths shall not be prematurely abandoned”. A closer analysis of this connection is left for future research.

reports, analogously to the standardized order of presenting a case at a law court. Due to this standardization, people with different viewpoints are able to contribute and collaborate.

Choosing by Advantages (CBA) is a system (Suhr, 1999) that directly considers (relative) advantages of alternatives and makes comparisons based on these advantages – rather than trying to present the advantages numerically along one axis (usually costs) (Arroyo, Tommelein and Ballard, 2014). It is now in common use in lean projects.

Classical rhetoric was seen by Aristotle as a way of presenting arguments to facilitate judgment. The method of Choosing by Advantages, in trying to simplify and display the crucial criteria for decisions, seems aligned with the Aristotelian goals for rhetoric. Indeed, Arroyo, Ballard and Tommelein (2014) argue that CBA provides the right framework to ask questions and find arguments to influence decisions. Especially, all options should be analyzed using *logos* (the facts and differences among the alternatives), *ethos* (the opinion of the relevant specialists about the impact of the advantage) and *pathos* (the sense of how this advantage will affect others). The authors thus state that the alternatives should be judged based on how they work, how they are perceived by expert judgment, and how they appeal to the users.

In conventional production management, the tendency is to assign problem solving to experts, who come up with a solution, documented through a memo. The selection among alternatives is carried either intuitively or using a method that converts the merits of each alternative into a single number. Although the mobilization of the knowledge of a wider group is in principle possible in both cases, there are hardly ways of doing it in a systematic and transparent way.

INVENTING

In the productive context, inventing can be interpreted as creation of new ideas for design and planning and problem solving. Classical rhetoric suggested finding ideas from “places”, *topoi*, regarding which the ancient rhetorical treatises gave extensive lists.

In lean construction, there is especially one method in use that is aligned to inventing: Target Value Design (Zimina, Ballard and Pasquire, 2012). In this method, a setting is created for a continuous, collaborative inventing of new improvement ideas. Arguably, the frequently and regularly updated cost information, providing visibility to the extent of improvements already achieved and to be achieved, feeds to the common ground of values held and facts known by parties involved in Target Value Design. Thus, although somewhat similar methods to *topoi*(such as TRIZ) currently exist, it is rather the basic rhetorical ideas related to common ground that seem to be used in lean.

In conventional production management, the expectation of creativity seems to be directed either to the early stages of design or planning, or it is secured by external experts, like in the case of value engineering.

CONCLUSIONS

The analyses made indicate that many aspects of lean, which as such have seemed odd and perhaps peripheral, can be explained through knowledge associated to the discipline of rhetoric. There is no evidence to claim that rhetorical ideas would have been deliberately used; rather it seems that in a search of working methods, solutions, which implicitly contain rhetorical ideas, have proven their superiority. In turn, conventional production management is characterized by an almost total absence of rhetorical mechanisms.

These initial findings are novel and important for the sake of theoretical explanation of lean; once again, it is found that lean subscribes to very different concepts and principles in comparison to conventional production management. The argument that in lean, a number of simple rhetorical mechanisms are widely used, will probably be helpful in the explanation and implementation of lean in the industry.

Moreover, the findings open up a new front for empirical research for assessing and determining the rhetorical phenomena in lean. Especially, it will be interesting to investigate and compare the use of rhetorical mechanisms in lean and conventional construction and determine their impact in terms of achieved outcomes.

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Christian, D., Bredbury, J., Emdanat, S., Haase, F. and Rubel, Z. Is Your Project Perfect? Using Four-Phase Project Delivery Analysis to Find How Far You Are From the Ideal State. In: *Proc. 23rdAnn. Conf. of the Int'l. Group for Lean Construction*, Perth, Australia, July 29-31, pp. 536-545, available at www.iglc.net

IS YOUR PROJECT PERFECT? USING FOUR-PHASE PROJECT DELIVERY ANALYSIS TO FIND HOW FAR YOU ARE FROM THE IDEAL STATE

Digby Christian[1], Jason Bredbury[2], Samir Emdanat[3], Frank Haase[4] and Zigmund Rubel[5]

ABSTRACT

This paper proposes a systematic approach for improving performance of any project regardless of type, location or jurisdiction. It focuses on assessing variances between the current state of an actualproject's delivery system and the ideal state using the framework of Four-Phase Project Delivery (4PhPD). This paper focuses on the questions that need to be asked and answered to uncover the key variances. Later, once these variances are assessed, customized strategies to reduce the variance can be formulated and introduced. The success of these strategies can be tested in further variance assessment iterations. Thus, a systematic continuous improvement strategy is created.

KEYWORDS

Theory, project delivery, kaizen, continuous improvement, lean construction

INTRODUCTION

Koskela and Howell (2002) in their conclusion pointed to the absence of any compelling theory of project management that could usefully be applied to help direct progress in project delivery. Additionally, nine years later, a research team at the Construction Industry Institute (CII) posited in their conclusion that an entirely new paradigm was needed to guide the implementation of successful project delivery strategies (CII, 2011). Also, it is true that there are at least six different ways of describing what a project delivery system is (Cho, et al., 2010, Table 1) and nine other ways of looking at project delivery systems in terms of contracting strategies

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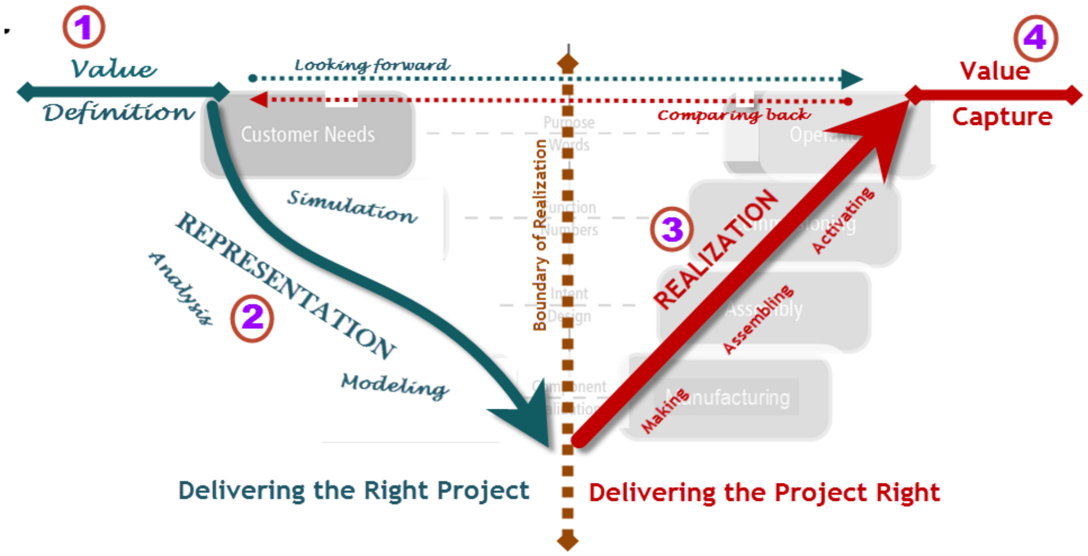
(Cho, et al., 2010, Table 2). However, the majority of these suffer from either being so general as to be difficult to build upon with pragmatic strategies or are so specific, they do not have broad applicability across project types.

Four-Phase Project Delivery (4PhPD) is a recent conceptual model (Christian, et al., 2014) that can be used to fill the theoretical void identified by Koskela and Howell (2002) and the CII (2011). Due to its broad applicability this model does not suffer from the shortcomings of the project delivery systems identified by Cho, et al. (2010). 4PhPD is summarized in Figure 1, below:



Phase 1: Value Definition. Is made up of the Human Concern, the Project Constraints & the Project Preferences.

Phase 2: Representation: Has to be analyzable against the Value Definition:

Phase 3: Realization. The Representation is realized and prepared for the Value Capture phase.

Phase 4: Value Capture. The Realized assets are activated to address the Human Concern.

Boundary of Realization: Point at which quantity & rate of resource consumption accelerates by greatest margin.

Figure 1

CII (2011) called for a new paradigm that would have Management by Means as one of its pillars. Management by Means emphasizes the abandonment of tight outcomes-based controls that react to deviations from the plan, and replaces them with a focus on the improvement of project processes, to reduce the chance that the project creates such deviations. The analysis proposed in this paper is essentially a Management by Means approach applied to the entire process involved in project delivery from inception to completion. The proposed process is also strongly allied with the fundamental lean concept of *kaizen* wherein "each incremental step in the continuous improvement process moves the process closer to the ideal state" (Stewart, 2011, pp.51). 4PhPD lends itself to this form of analysis as it explicitly describes the ideal state for each of its key phases. Within the process proposed in this paper, an ideal state is established and the distance of the current state from the ideal state is assessed.

SYSTEMATIC PROJECT DELIVERY IMPROVEMENT

4PhPD proposes the use of the lean concepts of ideal, current and future states to drive the improvement of any project delivery method. 4PhPD contains a definition of the ideal state and proposes that an assessment be carried out to arrive at the current state. Thus, by comparing the two states, a future state can be proposed that moves the current state toward the ideal state.

- The overall methodology for systematic project delivery improvement is:
- Describe the ideal state
- Identify the current state and assess its variance from the ideal state
- Describe a desired future state where the variance is reduced
- Identify a variance reduction strategy to get to the future state
- Implement the variance reduction strategy
- Repeat steps 2 through 5 as needed to optimally align value definition and value capture

Steps 1 and 2 are the subject of this paper. Note that the assessment does not derive numerical metrics as it is the effort to assess the variance of the current state from the ideal state that is important. There is no creation of some notionally objective number to represent the project's "idealness". Instead, guidance questions are provided that are worded so that all answers can be qualitatively assessed the same way. The more often something is true or is happening, or the greater the extent to which it is true or is happening the closer it is to the ideal state, and vice versa.

Steps 3 through 6 are implemented by project teams in their quest for improved outcomes. Since these steps will be very much customized for each project's individual needs and priorities, they are not the subject of this paper.

FOUR-PHASE PROJECT DELIVERY ANALYSIS

A project's delivery method is broken down into the four phases of 4PhPD and each phase is analyzed as follows:

VALUE DEFINITION PHASE

The Ideal State

"In perfect value definition every stakeholder is properly identified and consulted, and each describes their value needs from the project with perfect clarity" (Christian, et al., 2014). In other words, in the ideal state the project team not only understands exactly who the project stakeholders are, but also understands why the stakeholders need the project. Also in the ideal state the team can articulate clearly the stakeholder constraints, and they can predict with complete certainty how the stakeholders will evaluate various possible solutions to the human concern.

Assessing the Current State

Strategies for assessing various projects against this ideal state are explored in what follows. The strategies include analyses of a team's understanding of the four key areas of the value definition phase, namely, the project stakeholders, their human concern, their constraints, and their preferences.

Area 1: Project Stakeholders

Project Stakeholders are those whose interests are affected by the project, or those that have influence over the objectives and outcomes of the project. By identifying and engaging project stakeholders early, the project team would have the opportunity to understand the stakeholders' interests, their constraints, and their preferences. This understanding by the team would guide decision-making as solutions are explored and evaluated in order to find those that satisfy the human concern.

There are at least three main considerations when comparing the current state of stakeholder identification against the ideal state.

1. To what extent are clear criteria used to identify who the stakeholders are, and which of them would and would not be directly involved in defining the human concern?
2. To what extent is the impact of missing stakeholders in the value definition phase assessed and accounted for?
3. To what extent has the above information been documented, transmitted to and absorbed by the project team?

Area 2: The Human Concern

Projects exist to meet the needs of their stakeholders, and thus it can be argued that project teams who place emphasis on understanding the human concern are more likely to produce solutions that closely align with the project stakeholders' needs. Teams can consider developing metrics to define the human need and enable tracking and ranking of various options.

Areas 3& 4: The Stakeholders' Constraints and Preferences

Constraints are those non-negotiable needs of project stakeholders that must be part of the project team's solution to satisfy the human concern. Preferences, on the other hand, establish the criteria against which acceptable possible solutions can be ranked so that those most preferred are selected. Defining preferences using measurable values will help to rank and track preferences.

It is important to note that since projects are dynamic systems, the team's understanding of constraints and preferences will evolve during the course of the project. On some projects an attribute can start as a preference and later become a constraint and vice versa. The salient points to capture are: how well the team members agree on what constitutes a preference; what constitutes a constraint; and to what extent the team remains aligned with stakeholders as changes occur when the team evaluates alternatives, makes decisions, and makes trade-offs.

For the analysis there are at least four main considerations when comparing the current state to the ideal state with regards to the team's understanding of the human concern, project constraints, and project preferences:

1. To what extent do the stakeholders meet and mutually agree on the human concern, project constraints, and preferences, as opposed to meeting in a more fragmented fashion with the definition being an accumulation of potentially contradictory or incomplete definitions?
2. If efforts to attempt mutual agreement are made, how rigorous, reliable, and documented are those efforts?
3. To what extent are the aspects of the definition of the human concern, project constraints, and preferences specified in a way that could be quantified and measured?

4. To what extent has the above information been documented, transmitted to, and absorbed by the project team?

Without an explicit and clear understanding of the human concern and the stakeholders' constraints and preferences, project teams will find it more difficult to evaluate solutions, and will likely expend considerable effort in repeatedly engaging the stakeholders to validate their proposed solutions' fit against the human concern and the implicit preferences and constraints. More critically, if the evaluation criteria are kept implicit, the opportunities for optimization reduce, and there would be an increasing need to develop and present complete singular solutions versus solution spaces. The need to develop complete singular solutions contributes to over-production and increased rework when those singular solutions are found to be unsatisfactory by the stakeholders.

REPRESENTATION PHASE

The Ideal State

"During this phase solutions are represented perfectly and analyzed perfectly to verify with no chance of error that they meet the human concern, can be executed within the project constraints, and are compared against the project preferences to see which solution meets them most completely." (Christian, et al., 2014). Put another way, the ideal state of representation provides a foolproof way of predicting the future such that it is known with certainty during that phase that, once realized, the represented asset would yield precisely the desired value.

Assessing the Current State

Representation assessment is a combination of looking backward to the performance criteria of value definition (e.g. operational productivity, energy use) and project constraints (e.g. budget) and preferences (e.g. schedule – earlier is better) and looking forward to the realization phase (e.g. dimensional code compliance, constructability).

In the ideal state, representations are always as detailed as the later reality. The more detailed the representation the better since such detail inherently makes the representation more comprehensively and reliably analyzable backwards against the value definition and forwards against realization.

Assessment of the current state breaks down in to four primary areas of analysis. Three of these areas look backward at the value definition to evaluate the representation against the project constraints, project preferences, and human concern, and one looks forward to the realization phase, which evaluates the representation against constructability. Included in each of these four areas is an assessment of how well the team responded to the discovered variances from the ideal state.

Area 1: Analysis of the Representation against the Project Constraints.

There are at least six primary considerations:

1. To what extent is the project team aware of, agreed on, and reactive to the project constraints?
2. To what extent does the project team use the constraints to select viable solutions?
3. What is the level of detail of the representation of the physical scope?

4. What is the level of detail for any non-scope representation (e.g. line item budget, project schedule) that is used in the analysis against constraints?
5. How well connected to the scope representation is the non-scope representation? (e.g. is a detailed budget automatically changed every time a highly detailed representation is altered?)
6. How often are the representations analysed for conformance with the project constraints?

Area 2: Analysis of the Representation against the Project Preferences

There are at least five key considerations:

1. To what extent is the project team aware of, agreed on, and reactive to the project preferences?
2. To what extent does the team use the preferences to choose between solutions that satisfy the constraints?
3. How rigorous and reliable are the methodologies that analyzed the solutions against the preferences?
4. To what extent is the decision-making process that selected between solutions well documented, rigorous, and reliable?
5. How often are the representations analysed for conformance with the preferences?

Area 3: Analysis of the Representation against the Human Concern

There are at least four key considerations:

1. To what extent is the project team aware of, agreed on, and reactive to the human concern?
2. How rigorous and reliable are the methodologies that analysed the solutions against the human concern?
3. How often are the representations analysed for conformance with the human concern?
4. To what extent is a proxy human concern, whose satisfaction the project team has control over, used in place of the actual human concern, a criterion over which the project team has little or no control. For example, is "latest available medical technology" being substituted for "recruiting nationally recognized medical staff"?

Response to Variances

In the case of each of the three areas above, the way the team responds to variances should also be assessed. The following two questions can be asked:

1. How rapidly and completely does the project team respond to poor performance against the human concern, and against the project preferences, and to breaches of the project constraints?
2. How insignificant are the levels of rework associated with unsatisfactory levels of performance against the human concern, the project preferences, or with breaches of the project constraints?

Area 4: Analysis of the Constructability of the Representation.

There are at least six main considerations:

1. To what extent are rigorous and reliable systems and methods used to ensure what is represented is constructible?
2. What is the representation's level of detail when this analysis is performed?
3. How frequent are the iterations of the constructability analysis?
4. To what extent is this analysis undertaken by the people who would be responsible for project execution during the realization phase?
5. What level of detail does the representation reach just prior to transition through the boundary of realization into the realization phase?
6. How often are the representations analysed for constructability?

Response to Variances

As with the preceding three areas there are two key considerations:

1. How rapidly and completely does the project team respond to constructability issues?
2. To what extent have the levels of rework caused by constructability issues been minimized?

REALIZATION PHASE

Ideal State

"During this phase the selected solution is perfectly realized. It precisely aligns with the solution as represented in the representation phase. The solution is then activated so that it is fully ready for the value capture phase." (Christian, et al., 2014). In the ideal state, the realization phase has zero risk of failure because the representation was perfect and was analyzed to confirm with certainty that the value defined was intact and that the constructability was flawless.

Assessing the Current State

Realization can be split into two parts: First, the process of moving across the boundary of realization, and second, transforming representations of the project into tangible assets (see Fig. 1).

Area 1: Moving Elementsacross the Boundary of Realization

The Analysis

When moving project elements in the representation across the boundary of realization, the focus of the analysis is on the project team's recognition of the boundary's importance, and their actions in relation to this recognition. There are at least four main considerations here:

1. To what extent is the boundary of realization of each project element identified in the project's plan of work for each element?
2. To what extent has the project team identified for each project element the constraints and/or prerequisites that would allow movement across the boundary of realization with zero risk of rework?

3. To what extent has the project team successfully avoided rework by fulfilling the prerequisites, and removing the constraints identified in question 2, above?
4. Consider the sequence in which a project element moves across the boundary in relation to other preceding and succeeding project elements. To what extent has the team set up the sequence in a way that minimizes the overall risk of rework to represented and realized elements?

Area 2: Variances between Representation and Realization

The Analysis

There are at least four considerations here:

1. To what extent are rigorous and reliable methods used to identify variances between a realized element and a represented element?
2. How well understood by the project team are the root causes of the variances?
3. How rigorous and reliable are the methods which assess the impact of such variances on the value of the project as defined in the value definition?
4. How often is the realized aspect (be it scope, schedule, cost, or something else) compared to the representation?

It is important to note that the above considerations are not only applicable to the physical scope. The considerations are equally applicable to the represented construction work plan as compared to the actual realized construction sequence, or to the represented estimated cost of an element as compared to its actual realized cost.

Response to Variances

There are at least three key considerations here:

1. To what extent have the levels of rework in representation and in realization associated with such variances been minimized?
2. When a variance is discovered, how likely is it that an assessment of its impact on the value definition will be undertaken? And how thorough and reliable is that assessment?
3. Consider when the response to a variance is to change the representation rather than the realization. How rigorously was the impact of that change to the representation on the other unrealized project elements assessed?

VALUE CAPTURE PHASE

Ideal State

"During this phase the physical assets that were created and activated during the realization phase are used to address the human concern" (Christian, et al., 2014). In the ideal state, the value captured at the end of a project when the assets are put into operation aligns perfectly with the value defined at the start of the project.

Assessing the Current State

There are two main assessment questions for each of the three areas of constraints, preferences and human concern. These are:

1. How many of the quantified criteria defined in the value definition phase has the team been able to measure during the value capture phase?

2. How many of the non-quantified items has the team captured in a measurable way to inform future projects?

The assessment of the value captured covers the three areas of the value definition, namely the project constraints, the project preferences, and the human concern.

Area 1: Analysis of the Value Captured Against the Project Constraints

Beyond the two noted above, there are at least four key considerations here:

1. To what extent have the project constraints been complied with and, where they have been violated, how quickly were such violations discovered?
2. If constraints have been violated, how well has the team rationalized their decision to accept the solutions that do not meet the constraints?
3. To what extent have the impacts of any such violations been mitigated? For example, if the budget has been exceeded were any values tied to the human concern compromised?
4. To what extent have the impacts of the violations to any of the stakeholders been mitigated? For example, if the budget has been exceeded have measures been taken to minimize the impact on any other planned future projects?

The assessment of the impact of such violations to project constraints can be used to learn much about how important each project constraint actually was so that it can be emphasized more or emphasized less on the next project.

Area 2: Analysis of the Value Captured Against the Project Preferences

Beyond the two noted above under ‘Assessing the Current State’, there are at least three other key considerations:

1. To what extent were the project preferences satisfied?
2. To what extent did this level of satisfaction align with what had been predicted during representation?
3. To what extent are the stakeholders satisfied with project performance against the preferences?

Area 3: Analysis of the Value Captured Against the Human Concern

There is one key area to address, but it is perhaps the most important question to ask and assess on any completed project:

1. To what extent was the human concern addressed?

There are two additional questions for when a proxy human concern has substituted the actual human concern:

2. To what extent was the primary comparison against a proxy human concern?
3. How well did performance against the proxy human concern predict performance against the actual human concern?

In regards to this third question: if predictive performance is poor, then the key learning is to establish why it was poor, and what can be done better next time to create a proxy human concern that better predicts performance against the actual human concern.

CONCLUSIONS

This paper is a starting point for researchers and project teams who are looking to create assessment methodologies to analyze their project delivery methods with a view to systematic improvement in project performance.

Due to the broad applicability of the 4PhPD conceptual framework, any project can have its delivery method analysed in the way proposed by this paper to establish its current state for each phase; can assess how far that varies from the ideal 4PhPD state; and thus has the ability to establish strategies (Plan), execute them (Do), repeat the analysis proposed in this paper (Check), then start the cycle again (Act).

Finally, by using the common terminology of 4PhPD, such learning (about how to conduct analyses, and how to formulate and implement strategies) can be transmitted to, and absorbed by, many other project teams; and thus not only dramatically improve project delivery performance across industries and locations, but also the methods by which improvement strategies are formulated and implemented.

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CASE STUDY ON DESIGN MANAGEMENT: INEFFICIENCIES AND POSSIBLE REMEDIES

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ABSTRACT

Delivering better products with a reduced lead time and less resources has become the primary focus of design management. The aim of this work is to revisit typical design management inefficiencies and discuss possible remedies for these problems. To this end, a case study and interviews with seven Estonian architects were carried out. The data obtained was analyzed within the framework of the transformation-flow-value theory of production. Despite its failure to deliver customer value, a single-minded transformation view of operations has been the dominant approach taken in design management and processes, leading to inefficiencies in design practices.

KEYWORDS

Design management, design inefficiencies, TFV conceptualization.

INTRODUCTION

The delivery of better value to the client with a reduced lead time and less resources has become the primary focus of design management (Morgan and Liker, 2006). The dominant approach to design management and processes has been a single-minded transformation view of operations (Ballard and Koskela, 1998), leading to anomalies in design practices, such as large batches of work and/or rework waiting for information, poor specification of client needs and requirements, and poor generation and management of quality.

In this study, we revisit typical design management problems, in other words, waste, in the designing of buildings. To help illustrate current design management inefficiencies and processes, a case study involving an Estonian full-service design company was carried out, and interviews were conducted with seven architects.

In the first part of this paper, a theoretical framework for analyzing design practices is outlined; in the second part, the results of the case study and interviews are summarized; and finally, inefficiencies and possible remedies for the root problems are analyzed and discussed based on the transformation-flow-value (TFV) conceptualization of production (Koskela, 2000).

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NATURE OF DESIGN AND DESIGN MANAGEMENT

Design and engineering sciences have their origins in craftsmanship (Jones, 1992), which Aristotle classified as the practical knowledge of making, *techne* (Channell, 2009). In the early years of engineering sciences, the focus was on designing artefacts by applying the scientific laws and theories (Rankine, 1872). The 20th century saw the emergence of a design methodology, with a focus on the application of systematic scientific practices to engineering and design. Design science, popularized by Simon (1981), is a relatively new field studying design and design inquiry. One of the key ideas of design science was that design inquiry begins with the needs of the client. Thus, the main function of design inquiry is value generation for the client, and construction is the realization of a proposed solution with the lowest possible loss in value.

Since the 1960s, the development of design methodologies has been channelled by philosophical pluralism (Buchanan, 2009), which has shaped the inquiry of related subject matters, methods of thought and action, and the guiding principles of design. In his historical review, Buchanan (2009) distinguished three major strategies for inquiry: Dialectic, Design Inquiry (Rhetorical Inquiry and Productive Science), and Design Science. The origins of these strategies can be traced back to the ancient Greeks, whether theoretical and formal or practical and pragmatic. What distinguishes these different strategies is how the judgment of good or bad design is reached.

In the present work, the focus is on design inquiry, on both the act of designing and design as argumentation. More specifically, the TFV theory of operations management is used to study current design practices. Koskela has argued that the three different views must be seen as different dimensions of the same design task, as shown in Figure 1, and this is the reason why this theory is used as the basis for studying design management inefficiencies.

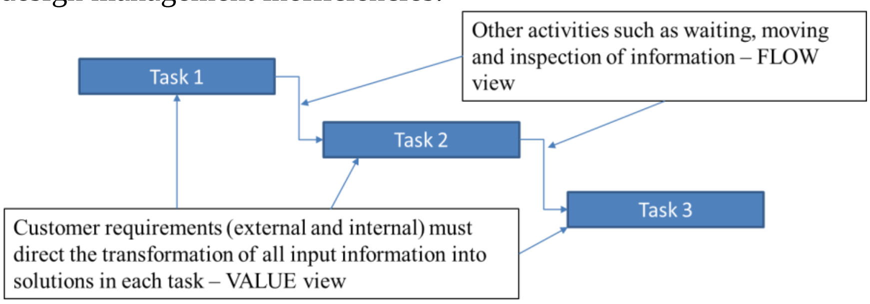

Figure 1. Simplified view of TFV conceptualization of design processes and tasks (Koskela, 2000).

The reductionist approach, called the transformation view, is guided by the principle of decomposition. The aim is to hierarchically break down the design tasks to optimize and control design task attributes, thus, focusing on control and risk reduction (Alberts and Hayes, 2003). The flow view is a practical and pragmatic process-oriented view, focusing on a timely sequencing of tasks and their interdependencies to optimize the design flow as a whole. According to the value view, which is driven by the customer-supplier relationship, customer requirements (external and internal) must direct the transformation of all input information into solutions for each task. Flow addresses the time-dependent complexity (tasks must be completed in the right sequence), and value generation addresses the time-independent complexity (Pennanen and Koskela, 2005).

The meaning of value is very broad and complex (Bertelsen and Emmitt, 2005), giving rise to a "wicked problem", as stated by Rittel and Webber (1973). Design problems can be wicked due to the instability of problem definition and the qualitative nature of value judgment in combination with quantitative objectives; for example, the client may prefer a product, which is not analytically the optimal solution. Additionally, design in the early stages of a process is inductive, and more than one solution exists to a particular problem (Pennanen and Koskela, 2005). Ballard and Koskela (2013) have argued that rhetorical methods could be used to derive the value judgments of a design solution.

METHODS

To understand current design management approaches and processes, a qualitative case study method is used to acquire context-dependent knowledge (Fellows and Liu, 2009). The lead author of this article observed and interviewed people in one of the leading design offices in Estonia. Seven Estonian architects were also interviewed to validate the observations made in the design office. This work focuses on the early stages of design and processes, including the pre-design (not explicitly but as implied by the consideration of the needs and requirements of clients), schematic design and preliminary design stages.

CASE STUDY AND INTERVIEWS: CURRENT DESIGN PRACTICES

OVERVIEW OF DESIGN OFFICE AND PROJECT MANAGEMENT ACTIVITIES

The design office in this study has the traditional hierarchical organizational structure, where designers and engineers work within their dedicated units. Work within a design unit is not centrally coordinated or organized but is the responsibility of the functional unit manager. In some units, work is highly specialized and standardized, in others, not: for example, in the architectural unit, one architect does everything within a project from beginning to an end, while in the structural unit, there are hierarchical levels of responsibility and specialization (the head of the unit, the head structural engineer, and three levels of technicians).

The design office has an ISO (International Standardization Organization) Certified Management System (CMS), which describes general business and project management processes. The "main processes", constituting only a small share of the whole set of processes, are design processes, which are the services they are selling to their customers and where value is created.

The design office has not specialized in any particular area. Project managers are not typically involved in the sales and marketing of the company's services. The architect, structural and building services engineer, and electrical engineer are involved only insofar as they provide an estimate of the resources (time) required to deliver a project. The final decision on pricing and estimates is made by a sales and marketing specialist, who also happens to be one of the owners of the company. Typically, under client pressure, project estimates must be reduced to win the contract, introducing uncertainty into the design. There is even more uncertainty when the office undertakes a project in an area in which it has no previous experience. According to the structural and building services engineer, these projects often cause many problems. Additionally, the architect and engineers feel that when they are responsible for only part of a design, there are also more problems than if the whole design were being done in-house.

In the CMS, design management is called project management. The description covers only those stages following the finalizing of the contract with the client. Project management is divided into phases with certain repetitive activities. The design project management model typically describes project evolution from the perspective of the company/design office, and the focus is on the outputs of each stage. This means that the project manager is expected to deliver a certain set of project documentation at the end of each phase. In the CMS, they do not further elucidate the design and engineering processes, phases, and activities, i.e., where the actual design takes place. The project manager does not usually interfere with the actual design process. The focus in project management is on planning and control. The latter means that the project manager prepares plans and during weekly project meetings makes certain that the designers are keeping to them.

Project stages and phases within the main processes are differentiated in terms of content and the level of detail of the documents produced, each of which are an attempt to get commitments to a progressively more detailed design in hopes of preventing backtracking. The content of design documentation at different stages has been standardized by the local “Building Design” standard (ECS, 2012), which, however, only stipulates the topics to be covered and not the actual content. The architect and engineers believe that the content of building information models (model element content and the level of detail) and quality could be more completely standardized.

MANAGEMENT OF MAIN PROCESSES

The description of the main design processes is based on observations made in the design office and interviews with all key staff, including the managing director and board member/sales representative/co-owner.

After the contract is signed, the project manager prepares the project schedule for the design work. Tasks in these plans are generic, simplified, and sequential and/or concurrent. Design progress is monitored at the weekly work planning meetings with the managing director, project managers and unit managers. Currently, there are no other systematic mechanisms in place for status reporting or progress monitoring, except in the case of the structural engineering unit. The head of the structural unit has implemented a cloud-based application called Todoist to create, assign, and monitor the daily activities of the structural engineer and technicians.

Work within the units is usually conducted in relatively large batches and iterations are avoided, as these are recognized as an inefficiency. As to the reduction of interdependencies in the design work, the architect and engineers have learned from experience what major problems may arise and have incorporated assumptions in designs to obviate late design changes. This approach seems to work relatively well, as the design team in this design office has worked together for many years and has learned to avoid certain problems. In the architect’s own words: “Over the years, we as a team have learned to avoid problems, as we have gained a better understanding of what the other units need or require from each other, and therefore, we can consider these in our designs!" Thus, according to the architect and engineers, the main reason for late changes is client behaviour.

ORGANIZATION OF DESIGN OPERATIONS

This section is based on two sources, observations and interviews carried out in the design office and interviews with seven Estonian architects, who have varied understandings of the architectural design process. One of the seven interviewed architects sees it as something unique to a particular project. The others believe that there is a common process, while what differs is the creative part of the work, which according to them, cannot be standardized.

The architects see the early design stages as their primary field of work. They work with the client and develop a design solution. Typically, at the beginning of a project some meetings are held to determine client needs and requirements, and then the architect works quickly to synthesize this information and come up with a design solution(s). Determination of the specification does not involve a very deep analysis of client requirements, and they are not broken down into functional requirements, rather the goal of the architect is to understand the design space and its boundary conditions in a broader sense. He/she usually begins with several concepts and then selects one to develop in greater detail. Only after the solution has taken more concrete form, does he/she go back to the client to have the solution approved. Usually, several iterations are required to come up with a satisfying solution.

Engineering specialists are not usually involved in schematic design. The architect may, however, consult with engineers on various aspects, such as structural scheme or space requirements for building services. Thus, the architect usually develops a conceptual design in isolation and principally with regard to functional space requirements and aesthetics. The structural engineer and building services engineer enter into the design process more systematically at the preliminary design stage. According to the structural and building services engineers, the design space is typically fixed for them, and they must then work with what they have. Since engineers may or may not be able to engineer a solution as the architect has conceived it (for example, when structural spans are too wide), negative iterations are sometimes needed at this stage.

Based on several interviews with architects and engineers, a typical design process, with design phases and activities, is shown in Table 1. The phases follow the chronological order of the design process and are conducted essentially in those batches. Intermediate coordination of the design disciplines is handled by the architects and engineers themselves.

ANALYSIS OF INEFFICIENCIES AND POSSIBLE REMEDIES

In this section we provide a summary of the design process and management related inefficiencies. We also look at possible reasons for the latter and propose possible measures for overcoming them. The testing of these ideas will be left to future research.

ORGANIZATION INEFFICIENCIES

Variability in projects

The observed design office works primarily on apartment, office and warehouse buildings, but it also often takes on atypical projects, introducing uncertainty: limited knowledge and experience in the design processes for a particular building type result in poor anticipation of possible problems, and the high learning curves demanded to develop technical alternatives and solutions lead to an overutilization of resources. Thus, atypical design projects lead to uneven demands (*mura*) and the overtaxing of resources (*muri*), resulting in process-related waste (*muda*) (Morgan and Liker, 2006). This is not to say that the design office should decline such projects, but rather that appropriate measures should be taken to manage them. The Last Planner System (Ballard, 2000a) and Agile design sprints (Sutherland, 2014) can be used to integrate and align the design production effort and to embrace possible variability.

DESIGN MANAGEMENT INEFFICIENCIES

Design as project management and its dual nature

Current design management methodology is based on project management techniques (the transformation view) developed in the 1950s and 1960s (Koskela, et al., 2014b). This highly idealistic management approach has caused anomalies in design production. Clark (1991) has reported the following problems in conventional design: difficulty in designing for simplicity and product reliability, excessive development times, weak design for constructability, inadequate attention given to clients (the specification of client needs and requirements is not recognized as adding value), weak links with suppliers (design subcontractors), and neglect of continuous improvement.

These failures are caused in part by neglect of the views of flow and value (Koskela, 2007). Due to the dominant role of the transformation view in design management, tasks are managed and optimized (in terms of duration and resources) in isolation and thus, the flow and value generation aspects of the design tasks are left for informal consideration by designers. If design is seen as a flow, there are four states of information (Koskela, 2000): transformation, waiting, moving and inspection. During the inspection phase, tasks are being checked to see how they conform and contribute to overall customer value; in the design context, this means design verification and validation (also known as evaluation).

Currently, only value-adding activities are systematically considered, and other activities, which do not directly add value, but cannot be eliminated, are not explicitly managed. This is evident when observing a typical schedule in the design office: only design validation is included in the project master plan, at the end of the typical design life-cycle.

Therefore, design management and organization have a dual nature, as these two are separate (Koskela, et al., 2014b). There are virtually two layers of organization, one focusing on planning and controlling, and the other, on getting the job done. The Last Planner System improves design production by integrating different planning and control solutions into a cohesive whole (Ballard, 2000a).

Table 1. Overall design process: stages, phases and activities

Design Stage	**Design Phase**	**Design tasks**	**Responsible person**
Schematic Design	Defining initial task	1. Collecting project information (surveys, geology, dendrology, site conditions, urban zoning requirements, etc.) 2. Defining initial task and design requirements (meeting or meetings with client) 3. Compiling design specification and confirming it with client 4. Exchanging initial ideas and discussing architectural design parameters	Architect
	Iterative development of design alternatives	**Spatial design and layout** 5. Generating ideas within and outside of the constraint space (the latter required for understanding other possibilities) – thinking and sketching go hand in hand (outside-in approach) 6. Testing ideas with BIM (inside-out) to ensure that spatial requirements are being met 7. Consulting with building services engineer regarding spatial requirements of technical rooms and shafts **Conceptual selection of façade solutions and internal structures** 8. Selection of element types and finishing materials (external and internal walls, roof, window, floors and shading) 9. General dimensioning of building elements 10. Iterating design alternatives with client (usually point-based approach)	Mainly the architect
	Finalizing the selected alternative	11. Further development of selected alternative 12. Modelling and visualizing selected solution 13. Agreeing on final schematic design solution with client	Architect
Preliminary design	Dimensioning and detailing of architectural solutions and preparing headnote	14. Consulting with structural engineer regarding conceptual structural schema and general dimensions of load bearing elements/layers 15. More accurate dimensioning of building elements and their components/layers (external and internal walls, roof, window, floors and shading) 16. Detailing of important building joints (e.g., parapet) 17. Agreeing with client on technical solutions	Architect
	Preparing a headnote for structural solutions	18. Specifying normative loads and live loads 19. Specifying conceptual structural schema and structural elements 20. Agreeing with client on technical solutions 21. Preparing headnote for structural project	Structural engineer
	Specifying utility solutions	22. Selecting solutions for connecting building with external utilities 23. Confirming designed solutions with utility owners 24. Agreeing with client on technical solutions	Building services engineer

	Preparing a headnote for building services	25. Specifying loads and requirements 26. Selection of energy supply type (including renewable energy) 27. Selection of distribution systems and end elements (diffusors) 28. Agreeing with client on technical solutions 29. Preparing headnote for building services	Building services and electrical engineers
	Energy certification calculations	30. Specifying energy related solutions 31. Specifying the thermal properties of elements for energy simulations 32. Calculations for energy certification	Building services engineer
	Building permit and hand-over to the client	33. Preparation of project documentation 34. Application for building permit 35. Handing project over to the client	Project manager or architect

Poor planning and avoidance of iterations

Typically, project managers prepare the project schedule, taking a top-down approach, where plans are developed first and then pushed down through the organizational hierarchy to the designers doing the actual design work. Schedules are prepared using two dependency types: sequential and concurrent (Eppinger, 1991). A third type of connection is an iteration (Lawson, 1980; Ballard, 2000b); two tasks are intertwined and mutually dependent on each other.

To reduce interactions and iterations, designers and engineers have incorporated assumptions into the design that safeguard against late design changes – negative iterations (Ballard, 2000b; Koskela, 2007). The longer the negative iteration is in the chain of interdependent tasks, the more rework it results in. These assumptions lead to over-designed artefacts with large buffers in solutions, causing contractors to optimize costs before or during construction.

Poor planning and simplistic scheduling have also resulted in the inability to monitor and systematically control design progress. When interviewing design office personnel, we found that the only monitoring process in place was the weekly project coordination meeting, organized to keep the company's executives up-to-date on project progression and solve important managerial issues. This has been causing poor or over-utilization of resources, as designers feel that their workload is fluctuating very widely.

The Last Planner System (Ballard, 2000a) and Agile methods (Sutherland, 2014) could be used together with BIM technologies to streamline the management and organization of design production, for establishing and aligning design and information flows to deliver client value continuously.

DESIGN ORGANIZATION INEFFICIENCIES

Poor specification of client needs and requirements

In the early design phases, the architect is primarily working with the client and developing a design solution. Usually, some meetings are organized to specify the client design space, but there is no clear specification of client requirements or control parameters, rather he/she typically hurries to synthesize the design (Ballard and Koskela, 1998). He/she is more interested in the spatial and functional design of the building, while other design criteria, such as cost, sustainability, energy efficiency, constructability, etc., are not considered explicitly but rather heuristically.

The current architectural design process suggests that the architect starts designing a particular type of building with some conceptualization already in mind, as stated by Lawson (1980); e.g., a general conceptualization of an office building and its spatial layout already exist, while the subject of the meetings for the architect is to identify and specify the boundary conditions. This design method has been considered a point-based method, where a designer after considering several alternatives, jumps to an idea (proposes a hypothesis), which he/she then starts to optimize through iterations with the client (Sobek, Ward, and Liker, 1999). In the philosophy of science, this approach is known as the hypothetico-deductive method of scientific inquiry (Losee, 2001).

Analysis of contextual aspects and client needs and requirements is necessary to move progressively through the induction process to design conceptualization, accepting that generic problem statements can be produced by considering the actual context and client problem (Koskela, et al., 2014a). Integrative design (Reed, 2009) and integrated design begin with the specification of client needs, requirements and project context in four domains (habitat, water, energy, and materials). The voice of the customer, quality function deployment, systematic workspace planning, and key performance indicators have been used to systematize the analysis and break down client needs and requirements, which can then be systematically pushed through the whole design process (Koskela, 2000).

Poor integration of design disciplines and decisions in the early design stages

Architects make design decisions on the basis of the function, image, and aesthetics of the object, letting them become fixed solutions, without fully realizing how these decisions impact building performance and other engineering aspects. Problem solving is pushed downstream with the belief that appropriate engineered systems can be developed.

The aim should be to push problem solving more upstream, as this would help to identify potential problems earlier, making it easier to make changes. Methods such as front-loading, set-based design, upstream problem solving, and concurrent engineering (not in terms of time reduction, but how it takes life-cycle into account) can be used within these methodologies. These approaches break up the long communication chains, and through collocation, information sharing, communication on design alternatives is instantaneous.

CONCLUSIONS

Based on the case study observations in the design office and interviews with architects, it is clear that many anomalies have been introduced into the system due to poor design management. Currently, the conceptual model for managing and organizing design is based on the transformation view of operations, with a focus on the planning and controlling of design production. The other views, flow and value, are decided informally by the designers. The focus on transformation activities, i.e., value adding activities, has led to inefficiencies: poor conceptualization of variability in projects, a virtual gap between management and production, poor planning and control, poor specification of client needs and requirements, and poor integration of processes and people. Many already existing and evolving concepts, methodologies and methods can be applied to reduce these inefficiencies. There is a need to view design paradigmatically taking into account all views: transformation, flow, and value.

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IMPROVEMENT OPPORTUNITY IN THE DESIGN PROCESS OF A SOCIAL HOUSING DEVELOPER

Claudio Mourgues[1], and Hugo Norero[2]

ABSTRACT

The design process in social housing projects includes several inefficiencies that impact not only the design itself but the whole project results. Part of the problem is that the design includes several non-value adding activities such as waits, design modifications, and rework.

Preliminary data from a case study in this research shows that deliverable control; work team coordination, communication and integration; personnel workload; and work planning and allocation are the main drivers of a good design in these projects. On the other hand, existing literature suggests the use of lean philosophy to improve the design but there is no evidence of how lean could be used in the context of social housing design. Therefore, this research assesses the most relevant drivers from the identified list for a case study and proposes and tests the use of Last Planner System and Collaborative Design to address these drivers to support social housing design.

The article describes the case study context and discusses the results from the interviews and surveys used to identify the main drivers for a good design. The article also proposes a lean design process and the validation methodology which is still to be implemented.

KEYWORDS

Social housing, lean design, last planner system, collaborative design

INTRODUCTION

Social housing projects in Chile are developed by social real estate management entities (EGIS, by its Spanish acronym), which establish contact with the future recipients of the state subsidies for the houses (future house owners) and support them during the whole process. This process usually goes from the organization of the group of individual owners to 9 months after the houses are delivered to the owners (MINVU, 2014). It is common to find EGIS that include the service of design and construction of the houses.

In this context, the design of the houses is basic, as the budget is very small and so, a same design – with small changes – is repeated in several projects. The limited effort spent in the design process affects not only the quality of the design but also the

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efficiency and effectiveness of the construction as the early project phases dramatically impact project performance (Kolltveit and Grønhaug, 2004).

Despite the impact that the design process has in the rest of the project, research on the management and engineering of this process has been limited (Freire and Alarcón, 2002). Several authors (Cornick, 1991; Austin, Baldwin and Newton, 1994; Koskela, Ballard and Tanhuanpaa, 1997; Ballard and Koskela, 1998; Formoso et al., 1998), referenced by Freire and Alarcón (2002), indicate that "planning and control are substituted by chaos and improvising in design, causing poor communication, lack of adequate documentation, deficient or missing input information, unbalanced resource allocation, lack of coordination between disciplines, and erratic decision making."

To reduce these problems, some authors have proposed the use of Last Planner^{TM} for the design process (Freire and Alarcón, 2002; Choo et al., 2004; Hamzeh, Balard and Tommelein, 2009). Other authors have proposed integrated concurrent engineering – an adaptation of extreme collaboration (XC), which is a design collaboration methodology developed at NASA (National Aeronautics and Space Administration) – to accelerate the design process (Chachere, Levitt and John Kunz, 2003; Chachere, 2009). Jara, Alarcón and Mourgues (2009), proposed an interesting combination of both approaches, using last planner to manage the design commitments and thus increasing the productivity and efficacy of the integrated concurrent engineering sessions.

This research aims at identifying main drivers of efficient design for social housing in Chile and assessing Last Planner^{TM} system and collaborative design to reduce an EGIS design problems. This paper presents the drivers and the proposal for the application and validation of these methods, as the application is still undergoing.

METHODOLOGY

The research is based on a case study where interviews – together with the literature review – provided key information to identify relevant factors for an efficient design process. The interviews included the four managers of the case study's company. Then, based on a survey applied to the case study, we chose the most important design factors for the company. Finally, to improve the design efficiency addressing the identified factors, we propose the use of two Lean Methodologies.

The validation of these methodologies is still to be implemented, and the methodology for this validation is described in the "Proposed Intervention" section of this paper.

SOCIAL HOUSING DESIGN – CHILEAN CASE STUDY

The case used in this research is an EGIS company that coexists with a construction company, which is a common case in Chile. This company develops and builds about 8 projects per year, ranging from 15 to 160 units, with an approximate annual revenue of 20 million USD. This company's design process usually is longer than the initially estimated duration, forcing an overlap between design and construction. The case study aims at understanding the causes of this problem and proposing/testing a solution.

First, we collected preliminary data that allowed us to identify factors that are relevant for an efficient design and the company's performance and improvement need regarding those factors.

RELEVANT FACTORS FOR DESIGN EFFICIENCY

Open interviews to the company's four managers – guided by the literature review – helped us to identify the following factors.

- Human resource quantity and quality: number of persons working in the design process with experience, skills and attitude proper for the work.
- Quality of design input information: clear definition of a client's requirements and scope.
- Personnel workload: amount of work that design workers are performing at the same time.
- Leader skills: soft skills such as proper decision making, empathy, being able to motivate, work coordination, conflict solving, etc.
- Coordination, communication and integration of the work team: how well the design team members relate to each other to perform their job.
- Work planning and allocation: analysis of dependencies and constraints in the design process in order to plan and allocate resources accordingly.
- Quality and quantity of infrastructure, equipment and tools: Proper relation between the needs of the design tasks and the amount and quality of resources such as physical spaces, computers, software, etc.
- Document management: being able to efficiently and securely create, find, distribute, review and store design documents.
- Deliverable control: systematic review of the deliverables to reduce design mistakes and omissions.

These factors do not intend to be a comprehensive list but they represent the view of the company´s managers about the drivers of design efficiency for their projects.

In order to assess the importance of these factors for the company's design efficiency, we applied a survey to the company's design professionals.

SURVEY

The survey asked about the need for improvement and the general performance of the company for each of these factors. These two questions try to gather the relevance of the factors from different perspectives. The first question (improvement need) emphasizes the implicit relevance of the factor in order to reach higher efficiency in the design process. The second question (general performance) assesses how well the company is doing related to that factor.

The respondents include 8 professionals that represent almost 73% of the company´s personnel involved in the design process (11 persons).

Table 1 shows the assessment of the company's improvement need for each of the identified factors. The survey asked the respondents to identify the three factors (without order) that the company needed to improve the most to have a successful design process.

Table 1. Survey Results for the Company's Improvement Need

Design Efficiency Factor	Respondents							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Work planning and allocation	1	1	1			1	1	1
Work team coordination, communication and integration	1	1	1	1	1		1	
Deliverable control	1	1	1					
Leader skills				1		1		1
Personnel workload					1	1		1
Quality of design input information				1	1			
Document management							1	
Human resource quantity and quality								
Quality and quantity of infrastructure, equipment and tools								

The assessment of the company's performance is based on a 5 point Likert scale where 5 is the worst behaviour and 1 is the best one. Table 2 shows these results.

Table 2. Survey Results for the Company's Performance

Design Efficiency Factor	Respondents							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Work planning and allocation	4	3	3	3	4	4	3	4
Work team coordination, communication and integration	4	3	3	4	3	3	3	2
Deliverable control	4	3	3	3	4	5	4	4
Leader skills	3	2	3	3	4	3	3	2
Personnel workload	5	1	5	5	5	5	1	1
Quality of design input information	2	2	4	4	3	3	3	3
Document management	3	2	4	3	3	3	3	4
Human resource quantity and quality	2	2	2	2	2	2	2	3
Quality and quantity of infrastructure, equipment and tools	2	2	1	2	1	2	2	2

Figure 1 compares the company's performance and improvement need regarding the design efficiency factors. The performance is calculated as the average of the responses shown in Table 2, while the improvement need is calculated as the percentage of respondents that identified each factor as shown in Table 1. Figure 1 also highlights the most relevant factors considering they either were selected by a majority of respondents in Table 1 or averaged a bad performance based on Table 2.

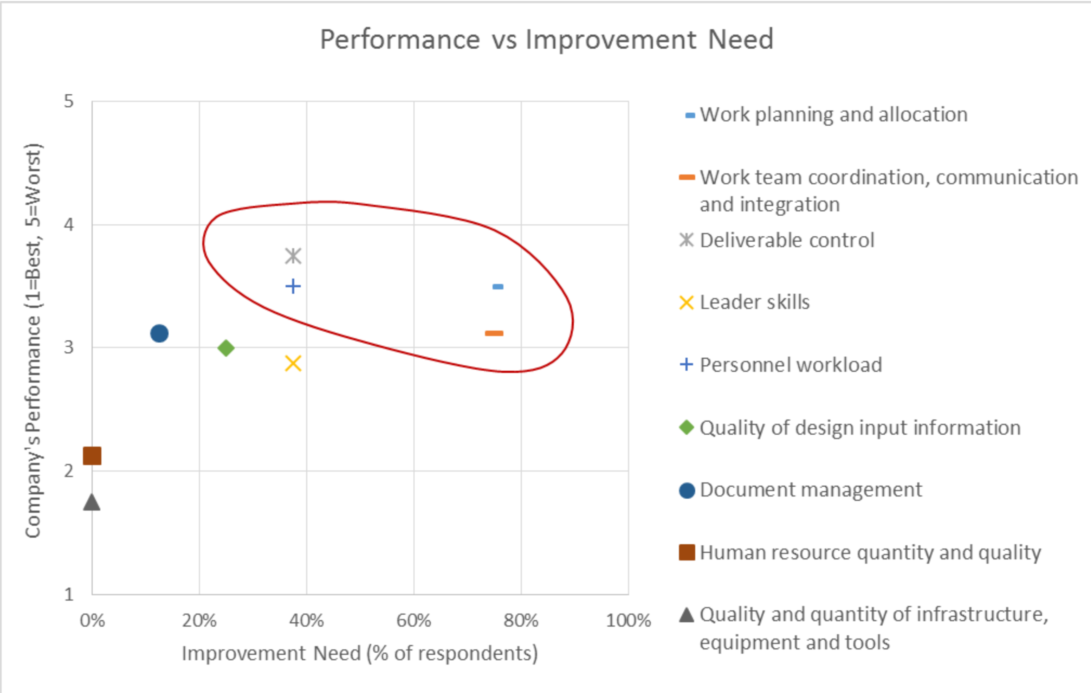

Figure 1. Company's performance and improvement need regarding the identified factors for an efficient design. Annotation highlights the most relevant factors.

Figure 1 shows that none of the design professionals consider that quantity and quality of both human resources and infrastructure, equipment and tools are part of the three most important factors that need improvement to accomplish an efficient design. At the same time, the professionals declare that the company is doing relatively well on those factors.

On the contrary, 80% of the design professionals that answered the survey considered the coordination, communication and integration of the work team, and the work planning and allocation to be within the three most important factors for an efficient design.

Regarding the company's performance, the respondents considered that the company's worst performance is on deliverable control, personnel workload, and work team coordination, communication and integration.

Design Efficiency Metrics

This study assesses the design efficiency as the duration of this process, considering a constant amount of design resources. The social design process includes two main phases: Design until delivery to SERVIU, and design from this delivery until final approval. SERVIU (Regional Service of Housing and Urbanism) is the state organism that approves the social housing projects. Figure 2 shows the data for 6 projects of the case study company. These projects are ordered chronologically with the newest projects to the right of the figure, covering a period of 5 years. The amount of design resources is considered the same for all the projects.

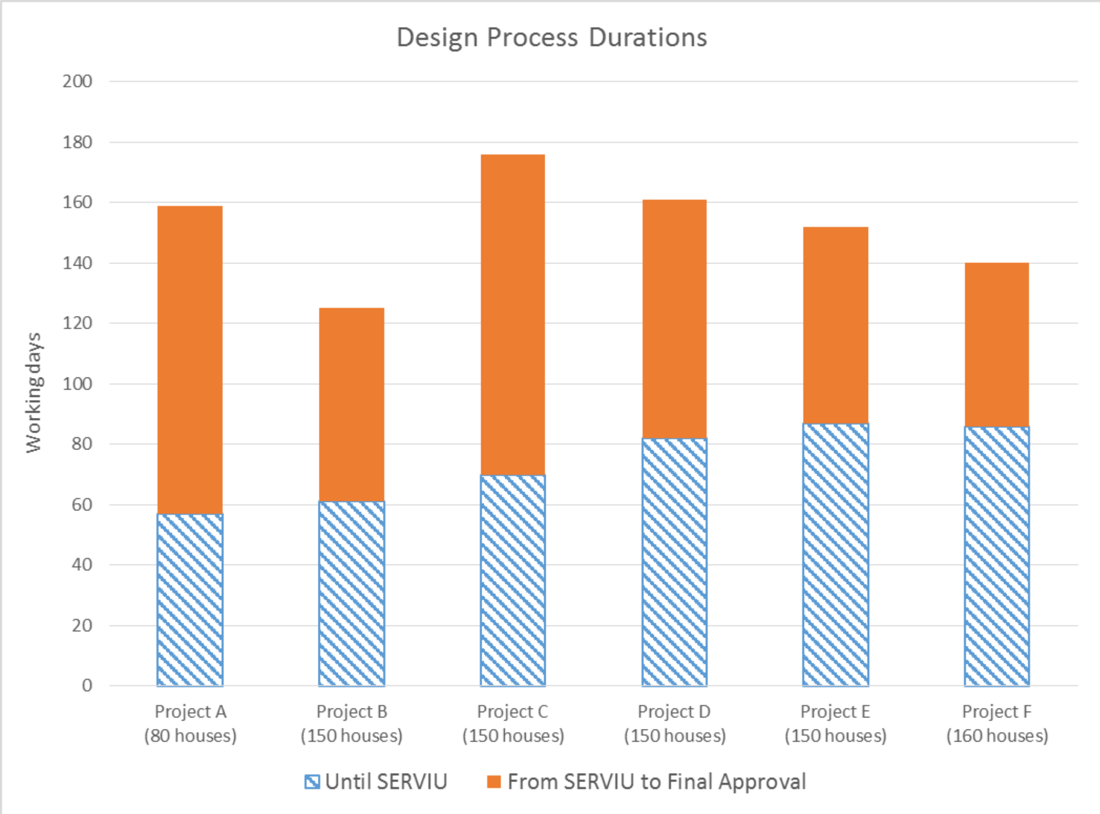

Figure 2. Duration of the social housing design process.

The projects include the number of house units to show that there is not apparent relation between number of houses and design duration. This is expected as even though there is certain design work related with the extension of the project (e.g., urbanization design), most of the work is focused on the houses but the same design applies to all the project houses.

Figure 2 shows an increment in the duration of the first phase of the design, i.e., all the work needed to present the design to the approving agency. At the same time, general duration decreases from project C. A possible interpretation of this incipient trend is that the longer process of preparing the design for the approving agency leads to a shorter review process and even total duration.

Despite this positive general trend, the company's managers consider that the total duration is still too long, which affects their competitiveness.

PROPOSED INTERVENTION

The next step in this ongoing research is to implement lean methodologies in the design process and compare the design efficiency metrics with the historic data.

Based on the results shown in Figure 1 and literature recommendations, we decided to implement Last Planner^{TM} System and Collaborative Design to address the most relevant factors for the design efficiency. The scope of this intervention is the first part of the design process shown in Figure 2: the internal design to prepare the information submitted to the approving agency (SERVIU). The next section describes this process with the proposed changes.

PROPOSED DESIGN PROCESS

The proposed process, depicted in Figure 3, aims at incorporating design collaboration sessions that are planned and prepared within the Last Planner^{TM} framework. The underlying idea is to use commitment management to facilitate the collaborative design (CD) sessions.

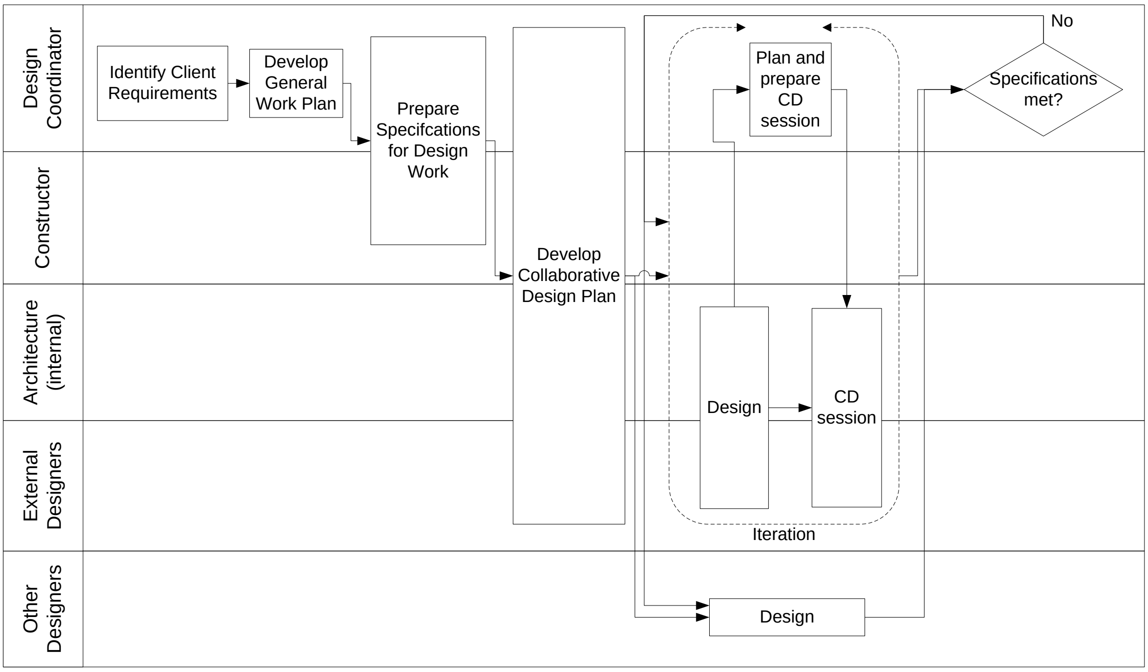

Figure 3. Proposed design process.

The process starts designating a design coordinator whose responsibility is to facilitate and ensure that the design plan is met. This coordinator must identify the client requirements and develop a general work plan. Then, using input from the constructor, the coordinator prepares the specifications for the design work.

The next activity is the development of the collaborative design plan. This activity is led by the design coordinator but all the design team must participate with the exception of designers whose work scope is very limited and does not considerably affect the project ("Other designers", in Figure 3). The collaborative design plan identifies parts of the design that would benefit the most from a collaborative approach. These parts of the design will be executed in the Collaborative Design (CD) sessions.

The CD sessions are work sessions (not coordination/revision meetings) of at least half day, where the designers meet to perform parts of their design work that are very interdependent with other parts of the design. These sessions are spread during the design period and alternated with regular design sessions where the designers perform work that does not considerably affect the others. Also, during the regular design sessions, the designers must prepare all the information they need to make the CD sessions productive. Here is where the last planner^{TM} methodology is used, led by the design coordinator, in order to ensure that design commitments are met by removing the identified constraints. The idea is that at the end of a CD session, the designers do a lookahead, identify constraints and make commitments to free certain constraints in order to be ready for the next CD session. The designers must free those constraints during the regular design period and the design coordination must facilitate that process. This design/CD-sessions cycle repeats until the design work is completed. In parallel to this cycle, the designers whose work is more independent (“Other designers”, in Figure 3) will perform their work in the traditional approach.

At the end of this design cycle, there is checking point where the design coordinator assesses the achievement of the design specifications. If there are observations, the process goes back to the design cycle.

PROPOSED VALIDATION

The validation has two parts: field-based and theoretical. For the field-based validation, we will apply the design process proposed above in one project of the company and compare the design efficiency metrics described previously. Ideally, more projects should be used for a more robust field-based validation but time and project availability cannot be guaranteed.

For the theoretical validation, we will carry out a charrette exercise with two groups performing the design for the same project but using different methods: traditional and lean. The scope of the design exercise will be limited so it can be performed in a reasonable amount of time (not longer than 4 hours). Therefore, the exercise will focus in the actual design, starting with a set of given specifications. The experiment subjects should be professional designers. This validation will allow to capture, besides the design efficiency metrics, other metrics such as interactions among designers, design quality, and variability of the results.

CONCLUSIONS

The preliminary data shows that the factors related with planning, coordination, communication and integration were considered the most relevant to achieve an efficient design. These factors are strongly related with the proposed methodologies: last planner™ and collaborative design. On the other hand, the company’s worst performance related to the control of the deliverables, personnel workload and work planning. Again, the proposed methodologies address these identified factors.

Some of the initially identified factors seem to be conceptually related, for example the amount and quality of human resources, work planning and allocation, and personnel workload. This conceptual relation does not affect the validity of the findings nor the proposed design process.

The context of social housing plays an important role in the identified factors as the tight budgets lead to a reduced investment in the design planning and coordination. This hinders the control of the deliverables and work assignments leading to personnel’s work overload. At the same time, the interaction with the groups of future house owners challenges the management of the design process.

Also related with the context of social housing, one of the main foreseen challenges is the alignment of the external designers. In this regard, designers for social housing projects usually are independent professionals or very small companies which presents a challenge to the implementation of the methodologies. The case study’s EGIS – in its owner capacity – plans to generate incentives such as long-term relations and methodology training. On the other hand, the discrimination between external and other designers (Figure 3) reduces this challenge.

Although the research is still ongoing and validation is yet to be performed, the company's managers positively assessed the proposal.

The expected outcomes of this research are efficiency and quality increments in the design process. These outcomes should reflect in a shorter duration for the overall design process – including the design until the delivery to the SERVIU and the SERVIU's review and its respective iterations – as it is assumed that a better design quality should facilitate the review process. This assumption may be affected by the project location (and then this variable is important for the field validation) as different SERVIUs differ in bureaucracy and requirement levels, which impacts the review process duration.

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IMPROVING DESIGN WORKFLOW WITH THE LAST PLANNER SYSTEM:TWO ACTION RESEARCH STUDIES

Sheriz Khan[1] and Patricia Tzortzopoulos[2]

ABSTRACT

Variability in workflow during the design stage of building projects has been widely acknowledged as a problem related to poor planning and control of design tasks and has been identified as a major cause of delay in building projects. The Last Planner system (LPS) of production planning and control helps to create predictable and reliable workflow by enabling the management of the range of relationships, interfaces and deliverables involved in a project. This paper presents results of implementing LPS in design to minimize variability in workflow within BIM-based building design projects. Action research was used to implement and evaluate the effectiveness of LPS weekly work planning (WWP) to improve workflow during the design development phase of two building design projects. The research was carried out with the collaboration between design practitioners at two building design firms in Florida and the researchers as facilitators. Overall PPC (Percent Plan Complete) measurements suggest that design workflow improved in both projects after WWP was implemented. However, efforts to use BIM in a lean way in the two projects (discussed in detail in an IGLC22 conference paper by the authors of this paper) were believed to be partly responsible for the improvement in design workflow.

KEYWORDS

Design workflow variability, LPS, BIM.

INTRODUCTION

Traditional design planning practice lacks a mechanism to manage workflow (Koskela, Ballard and Tanhuanpää, 1997). The planning of design tasks has traditionally been done from the top down with a project management team, consisting of a project manager and the lead designers (the architect and the engineers), meeting regularly to identify upcoming tasks on a master schedule and, without making sure that the tasks can actually be done, pushing them down to drafting (CAD or BIM) technicians to execute. The primary goal of traditional push planning is to finish design tasks by due dates as determined on the master schedule,

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design management being based on a drawing due date schedule and a summary drawing circulation list (Koskela, Ballard and Tanhuanpää, 1997). The order or timing of individual design tasks are not scheduled but left to be self-managed by each design discipline (Koskela, Ballard and Tanhuanpää, 1997). Traditional push planning is therefore not very reliable.

LPS has been applied very successfully in the past as a planning and control tool during the construction stage of building projects (Ballard and Howell, 1994; Koskenvesa and Koskela, 2012). However, the few reported applications of LPS during the design stage of building projects (e.g., by Hamzeh, Ballard and Tommelein, 2009; Bhatla and Leite, 2012; Wesz, Formoso and Tzortzopoulos, 2013) have been somewhat general in nature and limited in scope.

LPS has four planning levels: Master Planning, Phase Planning, Look-ahead Planning and Weekly Work Planning. At the WWP level, the right sequence of work and the right amount of work that can be done are selected (Ballard and Howell, 1994). LPS can help to increase task planning reliability and reduce workflow variability at the WWP level by filtering planned tasks to ensure that preceding tasks have been completed and by securing firm commitment of resources by the Last Planners (AlSehaimi, Tzortzopoulos and Koskela, 2013).

As a pull planning tool, WWP has been used very effectively in the past during the construction stage of building projects by the various building trades to plan and control their tasks collaboratively in order to increase task planning reliability and reduce construction workflow variability, but its application to design has not been so widely investigated. This paper demonstrates that WWP can also be used effectively during design by the various design disciplines to plan and control their tasks collaboratively in order to increase task planning reliability and reduce design workflow variability.

RESEARCH METHOD

Action research (AR) allows an existing solution, like WWP, to be evaluated in an organizational context, with the knowledge acquired from the implementation used to make recommendations for future application of the solution (Iivari and Venable, 2009). Researchers who adopt AR are likely to be practitioners who wish to improve understanding of their practice or more likely to be academics who have been invited into an organization by decision-makers aware of a problem requiring action research but lacking the requisite methodological knowledge to conduct it (O'Brien, 2001).

Using AR, the researchers worked closely with design practitioners to implement, monitor, and evaluate the effectiveness of, WWP during the design development phase of a building design project at two architecture/engineering (AE) firms in Florida. Design development is the phase of the building design process in which the preliminary design model, created by the architect during the schematic design phase, is shared with other members of the multidisciplinary design team to be used as a starting point for their specialized design input. It is also the phase that requires a tremendous amount of coordination of the efforts of the various design disciplines to finalize both form and function. The design development phase was scheduled to last sixteen weeks in both projects.

One of the firms is located in Melbourne and was designing a \$23.9 million, 14,865m², seven-story hotel to be built in Melbourne Beach, using the design-bid-build method of procurement. The action research study ran from May 2013 to August, 2013. The hotel design team consisted of a project manager, an architect, two intern architects (IAs), a structural engineer, a mechanical engineer, an electrical engineer, a plumbing engineer, four engineers-in-training (EITs), a BIM manager, and six BIM technicians.

The other firm is located in Fort Pierce and was designing a $13.6 million, 8,919m², six-story apartment building to be built in Sebastian, using the design-bid-build method of procurement. The action research study ran from July 2013 to October 2013. The apartment design team consisted of a project manager, the architect, an IA, a structural engineer, a mechanical/electrical/plumbing (MEP) engineer, three EIT, a BIM manager, and five BIM technicians.

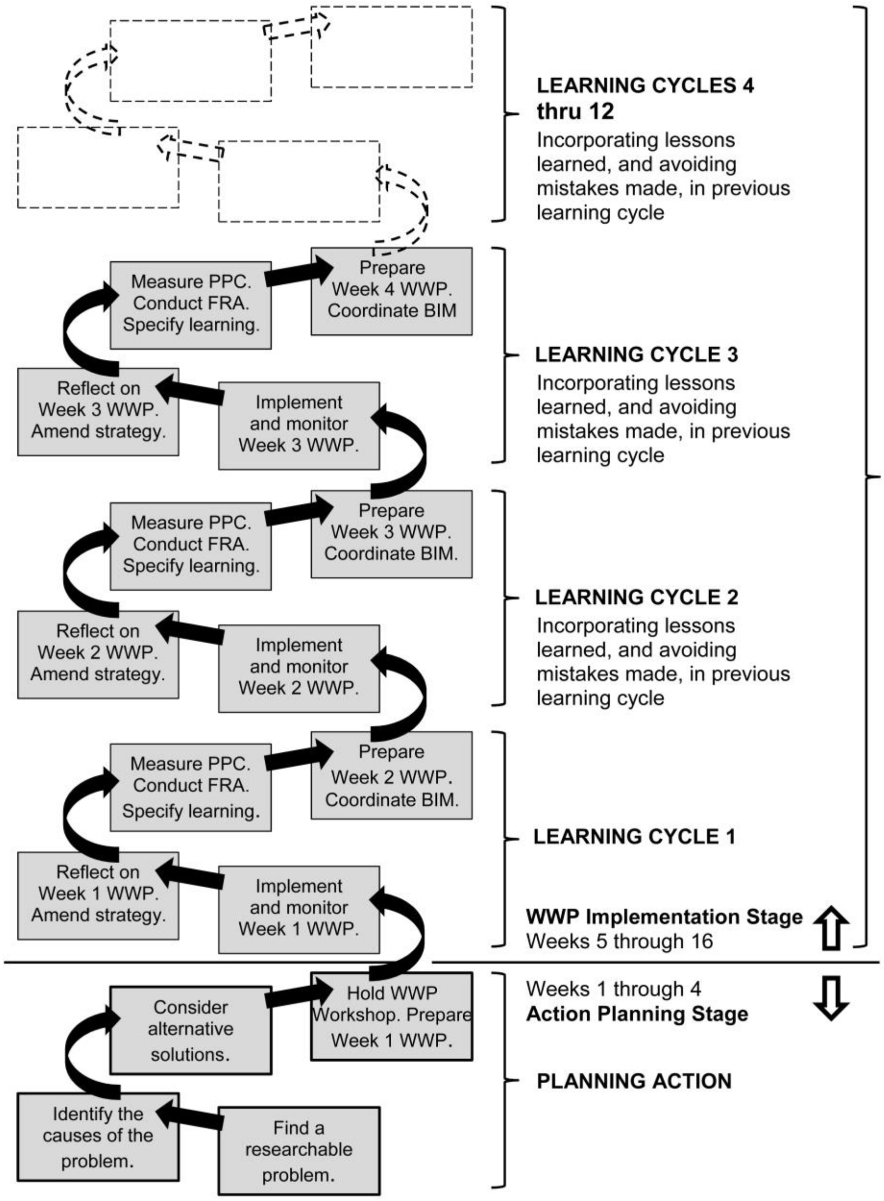

Figure 1: The action research spiral

The WWP planning/implementation/monitoring/evaluation process took the form of a spiral, as depicted as in Figure 1. The rising spiral of steps signified the learning acquired in each cycle and integrated into the next learning cycle, which resulted in a higher level of professional development that motivated the practitioners to set higher goals and reach an even higher level of professional growth. The effectiveness of WWP as a design planning and control tool was evaluated quantitatively using PPC and qualitatively using a questionnaire to obtain the views of the practitioners on the usefulness/effectiveness of WWP.

During the initial four weeks, an exploratory study was conducted at each firm to assess the current design planning practice, BIM usage and design workflow during the design development phase, suggest an alternative approach to improve them, if necessary, and train the practitioners to adopt the new approach. The exploratory study involved interviewing the project manager, attending four weekly task planning (WTP) meetings and observing the practitioners at work. PPC measures were also collected. Other methods used to collect data included literature review, document analyses, participatory observation, informal discussions, interviews and questionnaires.

RESULTS

THE OLD PUSH-PLANNING APPROACH

The exploratory studies revealed that both firms were practising the traditional top-down style of design planning shown in Figure 2. The project management team, consisting of a project manager, the project architect, the project engineers and the BIM manager, met each week to agree on the design tasks that *should* be performed in the coming week and, without making sure that they *can* be done, pushing them down with instructions and/or sketches to the IAs, EITs and BIM technicians to execute. The WTP meetings were characterized by informal conflict resolutions and commitments to accomplish tasks.

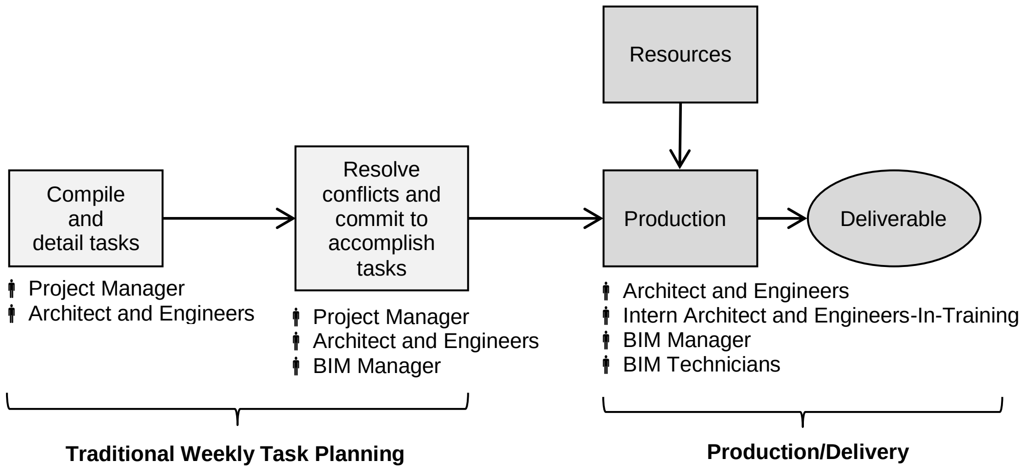

Figure 2: The old push-planning approach before adoption of the new approach

The IAs, EITs and BIM technicians were left out of the planning process. The tasks they were assigned to perform were taken from a master schedule prepared at the beginning of the design project, shortly before the schematic design phase began. Their primary goal was to finish design tasks by due dates dictated by the master schedule. The focus of WTP was therefore on project completion rather than on production control: the execution of individual design tasks was managed internally by each design discipline and coordinated externally with the other design disciplines in an ad hoc manner. This was a key cause of variability in design workflow.

Furthermore, the existing workflow at the two AE firms had been established over a number of years to produce a set of coordinated architectural, structural, mechanical, electrical, and plumbing drawings for building projects. The design process began with the architect, structural engineer and project manager conceptualizing the architectural form and structural system and then conveying the design to project engineers who followed through with designs and drawings.

In both projects, BIM technicians created 3D models of the different building systems from sketches and instructions provided by the architect and engineers, who did not have the skill to create the models themselves. Designers also had the BIM technicians extracting 2D drawings from the 3D models for review, quality assurance, quality control and communication with the client. This moving back and forth between 2D drawings and 3D models recalled the days when architects and engineers depended on draftsmen to generate drawings for them to communicate their designs. The firms had not moved beyond the old 2D drawing paradigm to the new 3D modeling paradigm associated with the most efficient use of BIM.

By itself, push planning is not an effective approach to task scheduling. However, it is necessary in building design, and failure to supplement it with pull planning essentially deprives building designers of a technique for producing desired results (Ballard, 1999). Based on the findings of the exploratory studies, the use of WWP collaborative planning was recommended to provide the push scheduling with the pull necessary to increase task planning reliability and reduce design workflow variability. The project managers agreed to try WWP during the final twelve weeks of the design development phase. Efforts would also be made to use BIM in a lean way in the two projects. A WWP training workshop was held for the practitioners, after which WWP was implemented for twelve weeks.

How The New Push-Plus-Pull Planning Approach Worked

In this approach, instead of a small exclusive project management team meeting to push tasks down to the IAs, EITs and BIM technicians be performed during the coming week, the entire design team met in the firm's conference room each Friday afternoon to participate in the design planning process and make commitment to finish the tasks on the master schedule that were to be performed in the coming week by agreed dates. Post-it sheets—a different color for each design discipline—were used to display the tasks and their prerequisite(s) and constraint(s) on a whiteboard.

The duties of Last Planners, the persons responsible for production unit control, i.e., the persons responsible for completion of individual tasks at the operational level (Ballard, 1999), fell naturally upon the lead designers (the architect and engineers) who, in consultation with members of all design disciplines, decided the tasks to be performed in the coming week, using a strict can-be-done filter in their selection. The Last Planners were therefore responsible for ensuring that the right sequence of work and the right amount of work that could be done are selected for the coming week.

The IAs and EITs were responsible for decomposing tasks a week in advance and proactively seeing that they were ready to be performed when scheduled, monitoring the progress of tasks daily, and performing Failure Reason Analyses (FRA), that is, investigating and logging on a FRA form the root cause of non-completion of any task. The lessons learned from the FRAs, otherwise referred to as root-cause analyses, were used to prevent similar problems from recurring. PPCs and FRAs were reviewed during the WWP meetings.

This approach (see Figure 3) avoided assignment of tasks that should be performed, but which were hampered by incomplete prerequisites or unresolved constraints. No task was scheduled unless an agreement was reached on who was responsible for timely prerequisite handover and who will perform the task and by when. If it was determined that more manpower or other resources would be needed to complete a task by a certain time, then more manpower or other resources would be allocated to that task.

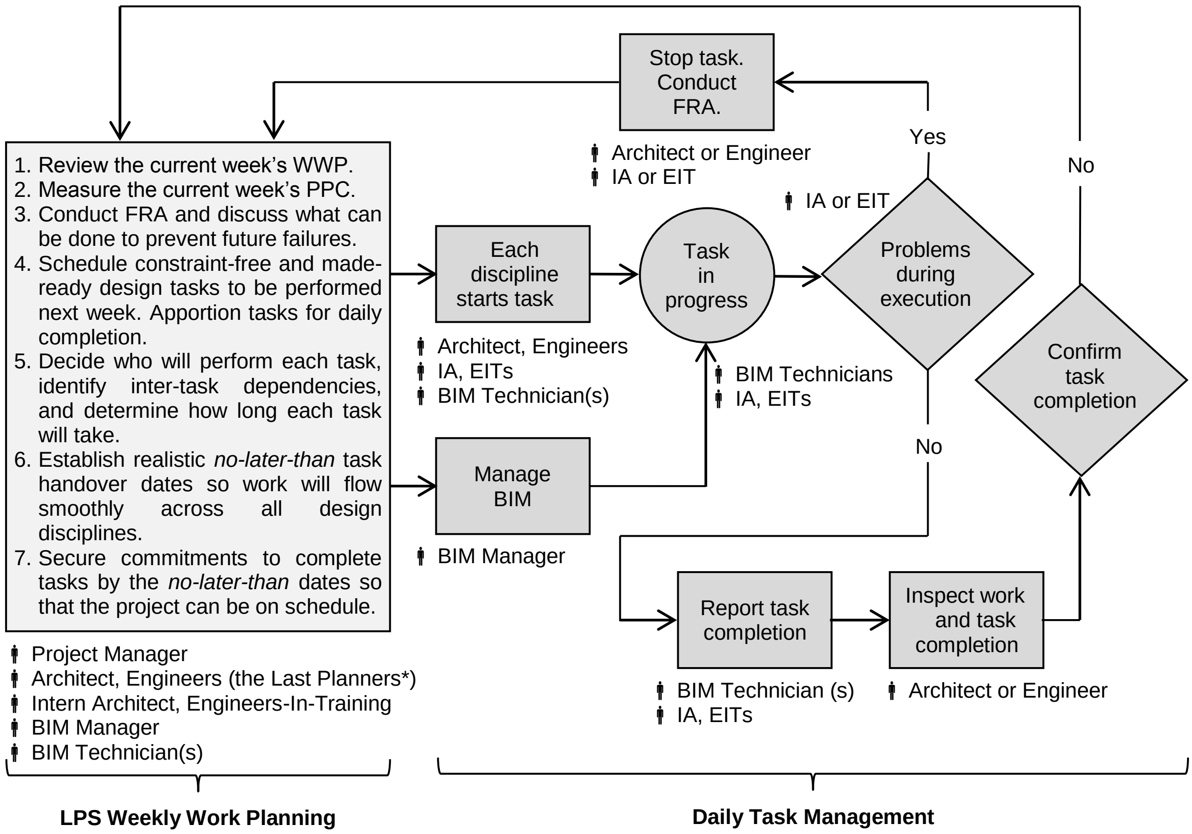

Figure 3: New push-plus-pull planning approach

PERCENTAGE PLAN COMPLETED

PPC measures served as a tangible incentive for the project teams to improve the predictability and reliability of the WWP and provided empirical evidence of the effectiveness of WWP as a design planning and control tool. As shown in Figures 4 and 5, in both projects, WWP PPCs were higher than WTP PPCs. There was 12% rise in average overall PPCs in the hotel project and a 14% rise in average overall PPCs in the apartment project, suggesting that there was an increase in task planning reliability and thus reduction in workflow variability during the WWP implementations. The hotel design development phase finished three days ahead of schedule, and the apartment design development phase finished two days ahead of schedule, which meant a 2.50% and a 3.75% increase in production cost efficiency, respectively, in this phase of the projects. According to the practitioners, this phase often finished at least one week after schedule.

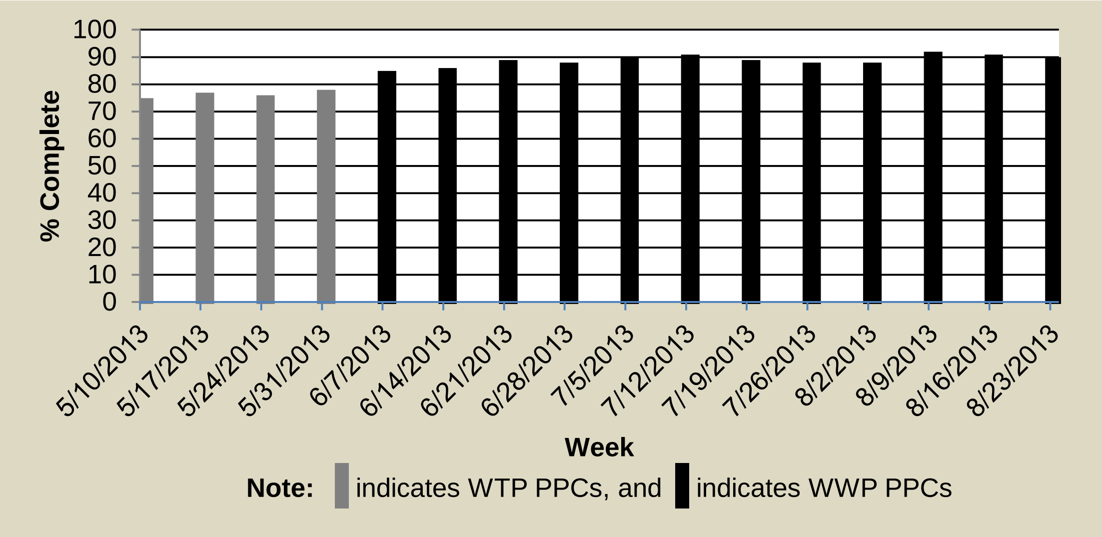

Figure 4: Percentage Plan Completed (PPC), hotel project

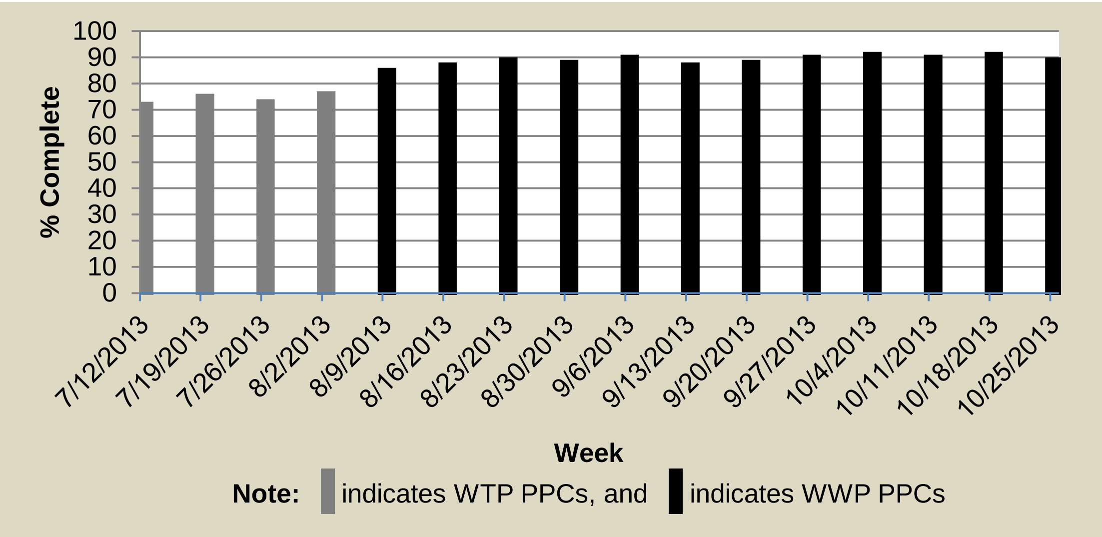

Figure 5: Percentage Plan Complete (PPC), apartment project

FAILURE REASON ANALYSES

A key feature of the continuous improvement process was the study of the reasons why tasks promised in the WWP to be completed by a certain time were not completed by that time. FRAs were conducted to help improve each weekly cycle of WWP implementation. This involved analyzing the causes of failure to complete daily assignments, thus facilitating learning from mistakes and helping to prevent those mistakes from happening again. The four main reasons for non-completion of assignments are shown in Table 1. Regarding the reasons for non-completion, the IAs and EITs explained that it would take some time and effort for all the practitioners to fully understand what they must do to maximize the value of pull planning.

Table 1: Number and percentage of occurrences of non-completion of assignments

Reason	Project			
	Hotel		Apartment	
	Occurrences	Percentage	Occurrences	Percentage
Waiting for prerequisite work	22	36%	20	38%
Insufficient input information	19	31%	13	25%
Underestimation of time	17	28%	16	31%
Rework	3	5%	3	6%

PRACTITIONERS' VIEWS OF USEFULNESS/EFFECTIVENESS OF WWP

Table 2 shows the responses of the practitioners in the two projects to some of the statements in a questionnaire regarding the effectiveness and usefulness of WWP as a design planning and control tool.

Table 2: Practitioners' Perceptions of the Effectiveness and Usefulness of WWP

Response / Statement	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	Total
LPS WWP was more effective as a design planning/control tool than traditional WTP.	29 (89%)	4 (11%)	0 (0%)	0 (0%)	0 (0%)	33 (100%)
Collaborative planning resulted in improved information exchange.	25 (76%)	8 (24%)	0 (0%)	0 (0%)	0 (0%)	33 (100%)
Make-ready planning resulted in improved information exchange.	21 (64%)	12 (11%)	0 (0%)	0 (0%)	0 (0%)	33 (100%)
Collaborative planning resulted in improved design workflow.	28 (85%)	5 (15%)	0 (0%)	0 (0%)	0 (0%)	33 (100%)
Make-ready planning resulted in improved design workflow.	23 (70%)	10 (30%)	0 (0%)	0 (0%)	0 (0%)	33 (100%)
PPC was useful as a reliable measure of design workflow.	24 (73%)	9 (27%)	0 (0%)	0 (0%)	0 (0%)	33 (100%)
FRAs resulted in improved project performance.	19 (58%)	14 (42%)	0 (0%)	0 (0%)	0 (0%)	33 (100%)

A follow-up interview with the two project managers in December 2013 revealed that the project teams continued to meet weekly during the construction documents phase as well; however, since this phase involved mostly the generation of construction drawings and specifications and very little designing, detailed design planning was not as critical to design workflow during this phase as it was during the design development phase. Similarly, in February 2015, in another follow-up interview, the project managers affirmed that they were convinced enough of the benefits of implementing WWP during the design development phase to continue applying it during this phase of future projects; however, they did not see much value in implementing it during the schematic design phase as this phase is predominantly the domain of the architect, is highly iterative and uncertain, does not require as much coordination between the design disciplines as the design development phase and, therefore, does not need as much detailed planning and control.

CONCLUSION

The results were consistent with those of previous similar research (e.g. Koskela, Ballard and Tanhuanpää, 1997; Ballard, 1999; Hamzeh, Ballard and Tommelein, 2009; Tiwari and Sarathy, 2012). WWP provided the practitioners in the two design projects with a systematic process of design planning and control that was focused on increasing task planning reliability and reducing design workflow variability. Teething problems aside, the practitioners soon recognized and appreciated the effect that WWP had in encouraging well-informed decisions and negotiations between them. WWP promoted richer collaboration and firmer commitment between the design disciplines. Drawing on their own experience and knowledge and on those of the other practitioners, the practitioners interacted and exchanged information as they moved through their tasks, allowing for greater integration of overall team effort. WWP ensured that every practitioner had a voice in the planning process, with the right to speak up and say whether or not a task could be completed by a certain time and with the responsibility to make commitments to finish tasks by a realistic time. This had a positive effect on the morale of the design teams.

Based on the knowledge gained in this research, the following steps are recommended for the successful implementation of WWP in building design projects:

- Secure the trust, interest and cooperation of the project manager in the new process (In this research, the fact that the researchers were themselves experienced architects went a long way toward securing the goodwill of the project manager).
- Conduct an exploratory study to assess the current design planning practice and workflow and determine whether WWP alone would be the most practical level of LPS to implement and would produce the most improvements without disrupting the master schedule.
- Hold a training workshop to familiarize the practitioners with WWP and its benefits and to prepare them to apply it.
- Assign roles and responsibilities that match the skills and background of the practitioners (In this research, the lead designers were natural candidates for the Last Planners role, and the IAs and IETs for the troubleshooting role).
- Include those practitioners who are responsible for performing the tasks in the task planning process (In this research, the active participation of the IAs, IETs and BIM technicians in the task planning process helped immensely to make task planning more realistic, more predictable and more reliable).
- Decompose tasks a week before their expected execution date and proactively make them ready to be performed by their *no-later-than* dates.

- Select for execution the right sequence of tasks and the right amount of tasks that can be done, thus avoiding assignment of tasks that ought to be carried out, but which are hampered by unresolved constraints.
- Obtain commitments from practitioners responsible for performing the tasks that they would complete the tasks by agreed-upon *no-later-than* dates.
- Monitor the progress of tasks daily to make sure that they are not waiting on prerequisite work and that they are not hampered by unforeseen constraints. In this way, tasks will proceed as scheduled and will be completed by their *no-later-than* dates (In this research, this duty was assigned to the IAs and IETs—excellent training for future Last Planners).
- Identify causes for non-completion of any task that was selected for execution and avoid repetition of those causes in future implementations.

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LEAN DESIGN VERSUS TRADITIONAL DESIGN APPROACH

Thea S. Munthe-Kaas[1], Hallgrim Hjelmbrekke[2], Jardar Lohne[3] and Ola Lædre[4]

ABSTRACT

The purpose of this paper is to determine if lean design can enhance value for the customer in the construction industry based on an examination of the design phase. Resent research from Statistics Norway shows a reduction of 9 % in the Norwegian construction industry's productivity from 1992 to 2012. The paper also discusses if lean design can have an overall positive effect on the productivity. A case study has been carried out, comparing two projects using a qualitative approach. The projects use different methods in the design phase; lean design vs. traditional design approach.

Implementing lean design can increase value for the client. Lean design might enable a productivity growth in the Norwegian construction industry similar to the growth observed until the 1990s. Similarities are found between classic project execution and projects where lean design is implemented, particularly the focus on planning and control. The originality lies in comparison of the recently implemented lean design and the classic project execution model. This permits an in-depth analysis of the novelty and effects of certain lean design features. Lean design seems to have reduced waste in the process, but the total value concept was rarely considered.

KEYWORDS

Value, lean design, productivity, lean construction, waste.

INTRODUCTION

Project management have traditionally been concerned with cost, time and quality when measuring success in a project (Atkinson, 1999; Cooke-Davies, 2002; Hjelmbrekke, et al., 2014). According to Fewings (2013) time, cost and quality are the three dimensions of control and represent the specific project efficiency factors. He further claims they are managed for the satisfaction of the customer's requirement, but are secondary to the customer's business needs. The prime concern for the project manager in a construction project is rather to create value for the customer.

Resent research from Statistics Norway shows a reduction of 9% of the productivity in the construction industry in Norway over a time period from 1992 to

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2012 (StatisticsNorway, 2015). The statistics also show an increase in the productivity in the manufacturing industry over the same period of time. Errasti, et al. (2007) claim that this increase results from integrated flows and processes in order to create value for the customer. They conclude that the construction industry has a lot to learn from this culture. This might also indicate that the construction industry has great potential for improvement.

In recent years, working methods such as lean construction have been introduced in the Norwegian construction industry. LCI (2015) defines lean construction as a production management based approach to project delivery. They further claim that the reliable release of work between specialists in design, supply and assembly assures value is delivered to the customer and waste is reduced. Emmitt and Ruikar (2013) argue that to ensure that maximum value is created and waste eliminated, the design phase must be managed effectively.

The literature review preceding this paper found a surprisingly small amount of studies devoted to the comparison of traditional and lean design approaches in light of value creation. To fill this knowledge gap, that is, to evaluate if lean assures added value is delivered to the client, it is essential to compare lean to the existing approach.

The study is based a comparative analysis of Bergen Academy of Art and Design (the Academy) and the New Norwegian National Museum of Art, Architecture and Design (the Museum). The Academy implements lean design while the Museum uses a traditional project execution approach. The ambition of this paper is to assess to which extent lean design can enhance value for the customer in the construction industry based on an examination of the design phase. It is examined how the distinctive stakeholders deal with the value specification as an outcome of the architectural competition. In order to address this issue, we attempt to answer the following two research questions.

- What are the characteristics of the two different design approaches?
- What are the advantages of the different approaches?

METHOD

The study leading up to this paper was based on a qualitative research method. A case study approach was chosen, in accordance with the procedures outlined by Yin (2013), examining two major construction projects in Norway. A literature study aiming to identify main features of project planning using lean design principles was carried out. The objective of the analysis was to compare these with design phase principles used in so-called traditional project planning within the Norwegian context. Several scientific databases were searched in order to identify papers bearing on lean design, value, value creation and design approaches to compare traditional and lean design in this context. A document study was executed on both projects. A pilot study of the Academy was conducted in the fall 2014, with three interviews. The pilot study was later used to shape the research questions in this article. The case study of the Museum and the Academy was carried out in the spring 2015. Five semi-structured open-ended interviews were carried out with the project manager in the Museum and senior design managers from the architects and the consultant engineers of both projects. The plan for future research is that this paper forms part of an on-going research of lean projects in the Norwegian context.

THEORETICAL FRAMEWORK

VALUE

The fundamental purpose of a project is to create value for the customer. Not surprisingly, value discussions constitute a major role within lean theory.

Several definitions of value with different perceptions exist. Kelly, et al. (2004) define value as function divided by cost. Bowman and Ambrosini (2007) on the other hand look at customer value as consumer surplus. Consumer surplus is defined as when a consumer derives more benefit (monetary value) from the good, than the price they have to pay. In this way it is distinguished between how the customer values the good and the actual price. Emmitt and Ruikar (2013) define value as a measure of the beneficial return gained from the consumption of resources.

Hjelmbrekke and Klakegg (2013) define value creation as a result of human activity. Thyssen, et al. (2010) maintain that during the construction project the involvement of different stakeholders will change and also their values and perspectives. Due to the change process and the nature of human behaviour, the change of perspectives will be unpredictable. This makes value management in construction a difficult process. Hjelmbrekke, et al. (2014) claim that in a construction project, value can be separated into the project output value and the use value. The project output value is the building measured on cost, time and quality. The use value is the effect of the project output on the core business. It reflects what the client is prepared to pay for the finished product when the various solutions are known. It is essential to consider how the customer evaluates the product to meet their needs (Hjelmbrekke and Klakegg, 2013).

Value and lean

LCI (2015) defines value as what the customer wants from the process. Salvatierra-Garrido and Pasquire (2011) recognise that the lean construction perception of value has, to a great extent, been influenced by lean production as manifested in the manufacture industry.

Koskela (2000) identifies three main causes that decreased value for the project customer: value loss due to poor project management, value loss due to design and value loss due to construction. He further claims that customer requirements can be unclear concepts that need to be addressed through the whole life cycle in the construction project.

Hines, et al. (2004) highlights that lean construction has developed from a waste reduction focus to a focus on customer value. They maintain that value for the customer can be increased by reducing internal waste, develop customer value or both.

Emmitt, et al. (2005) define value as "*an output of the collective efforts of the parties contributing to the design and construction process; central to all productivity; and providing a comprehensive framework in which to work".* They separate the perception of value into two conceptual phases: value design and value delivery. In value design it is established and reflected alternatives for conceptual design. By attaining agreements between participants and providing the best design solution, the uncertainty is reduced. In value delivery the chosen design alternative is transformed into a production design. The aim is to deliver the specified product in the best possible way, with minimum waste.

Salvatierra-Garrido, et al. (2012) found in their research of the value concept as commonly perceived within the IGLC community, most efforts have mainly been endeavoured to deliver value at project level, where waste reduction and planning and control of construction site activities have been key activities linked to value. Several efforts have endeavoured to fulfil particular customer's requirements. A reason for this might be that it is easier to consider and measure waste in a project that consider value, since value is a complex concept.

The client wishes to both increase the total value and reduce waste. In this paper value is assessed from two different perspectives; increased use value to maximise consumer surplus and increased consumer surplus by reducing waste.

PRODUCTIVITY

Productivity can be defined as a measure of the ratio between produced quantity (output) and input (Forbes and Ahmed, 2011). An increase in the productivity implies that a certain amount of input enables the production of more quantity than earlier. In the construction environment productivity may be represented as the constant-in-place value divided by inputs such as the cost value of labour and materials (Badiru, 2005; Forbes and Ahmed, 2011). Forbes and Ahmed (2011) state that recognizing the need for improvement through productivity measurements, performance improvement over time can be achieved. Oglesby, et al. (1989) maintain that traditional construction management tools do not address productivity, mainly just cost overruns and schedule slippage. Forbes and Ahmed (2011) maintain that performance is often measured in terms of completion on time, meeting construction codes and within budget. By just meeting the construction codes, the owner/client satisfaction is rarely considered.

In this paper productivity functions as the constant-in-place value divided by inputs. By reducing waste in the process, an increase in the productivity might be achieved. An increase in the productivity will thus affect the project output value.

DESIGN APPROACHES

Traditional design approach

PMI (2013) identifies tasks for the planning process group to develop a project management plan, plan scope management, collect requirements, define scope, create a Work Breakdown Structure (WBS), define and sequence activities, estimate activity resources and duration, develop schedule, plan cost management, estimate costs, determine budget, plan quality, develop human resource plan, plan communications, plan risk management, identify risk and perform risk analysis, plan risk responses, plan procurements and stakeholders management. According to Wysocki (2014), in traditional planning a central element is the Joint Project Planning Session (JPPS) where stakeholders up front develop the detailed plan. The end result is an agreement on how the project can be accomplished within the specified time frame, budget, resource availabilities, and according to client requirements. The deliverables from the JPPS are WBS, Activity Duration Estimate and Resource Requirements. A Project Network Schedule can be created from the WBS. It defines the sequence in which the project activities should be performed. The output of the activity schedule will be the assignment of specific resources to the project activities.

Lean design

Forbes and Ahmed (2011) maintain that in lean design constructability reviews and value engineering are continually integrated with decision-making. This is achieved with cross-functional design teams that include architects, engineers, contractors, and subcontractors among others. Emmitt, et al. (2004) found that through the use of creative workshops, which encourages open communication and knowledge shearing, the project participants claimed that the lean design process was contributory in delivering value and improving productivity.

Fewings (2013) claims that when front-loading the resources in design in order to eliminate waste efficiently in manufacture, success can be obtained. Such front-loading can be achieved by doing the planning ahead and arranging simultaneous working between the design, manufacture and supplier. To have a reliable database of products, systems and components is of importance in order to use learned systems for new products and design. Ballard (2008) highlights that it is central that the customer gets involved early in the process. The customer should be shown different alternatives for realization of their purposes and be helped to understand the effects of their requests.

Different tools often used in lean design are Target Value Design (TVD), Set Based Design (SBD) and Choosing by Advantages (CBA). The Last planner system (LPS) is a collaborative and commitment based planning system. Last planner system is based on the Should-Can-Will-Did principles (Ballard, 2000). According to our understanding, LPS can be divided into four levels of scheduling and planning notably master schedule, phase scheduling, look-ahead planning and weekly work plan (Ballard and Howell, 2003; Ballard, 2000). Learning is a significant part of LPS (Ballard, 1999; Ballard, et al., 2003; Ballard, 2000). Reasons for non-completion can be identified through Plan Percent Complete (PPC) (Ballard, 2000). PPC measures the percentage of task completed relative to the planned tasks. It is a measure on how well the planning system is working (LCI, 2015).

FINDINGS

There were only considered qualitative data in this comparison, due to the lack of available quantitative data.

Table 1: Overview of the distinctive projects

Facts	The National Museum of Art, Architecture and Design, Oslo	Bergen Academy of Art and Design
Design Approach	Traditional Approach	Pilot project in lean design (detail design)
Cost framework	5.327 billion NOK (01.07.2013)	1.065 billion NOK (01.07.2014)
Volume	Ca. 54,600 m^2	14,500 m^2
Construction start/end	2014/2019	2014/2017
Phase spring 2015	Detail design/construction	Detail design/construction
Client/Owner	Ministry of Culture/Statsbygg	Ministry of Education and Research/Statsbygg

BERGEN ACADEMY OF ART AND DESIGN

In the Academy, the design team consists of the architect Snohetta and the general engineering consultant Ramboll. Statsbygg decided to implement lean design in the detail design phase to improve the process. The design team was given intensive courses to be familiar with lean construction principles, but neither the course holder nor the design team had any experience with lean design. Statsbygg regarded the project as a pilot – and a specific model of how to implement lean design was established. The project was divided into four levels of planning:

- Level 1 it was the project level where there was prepared a Product-Creation-Process (PCP)-plan. This was a static model with sub-processes. The PCP-plan contains few milestones with wide timespans. Responsibility and rolls were defined at a general level.
- Level 2 was the sub-processes of the PCP-plan. An example of a sub-process is the designing. The design plan was divided into parallel and sequential task with milestones. In this level the responsibilities and rolls were distributed.
- Level 3 was a multidisciplinary theme. It described what the product was and when it was needed. One person was responsible for each theme and in charge of "pulling" in the information.
- Level 4 was a disciplinary activity.

Each phase in level 3 comprised a sequence of 14 days workload. The design team had a time-restricted co-location, where owner, consultant engineer and architect were located in the same office three days every 2nd week. The co-location included reserved time for the stakeholders and project team to report what they had done, what the issues were and what information was required. Visual planning was used. Meeting minutes were used sparingly – mainly theme logs with connecting deadlines.

There was a focus in the project to establish lean as a planning culture where mind-set, a course of action, a way of being or an attitude change, were essential aspects. TVD, SBD and CBA were not considered in the project, even though there were used some elements of these.

The breakdown structure in the detail design clarified the distribution of responsibility. This had a positive influence on keeping the right pace and flow in the project. The team kept up with deadlines. The decisions were made in plenary sections with the owner (Statsbygg) as the main responsible. The design team used a common BIM model for quality control and clash detection to obtain zero defects. The common BIM model ensured transparency, which created pull in the project. A good planning process and frontloading resulted in what was regarded as success. There was a mutual agreement that the use of lean methodology resulted in a good team spirit and teamwork. The time-restricted-co-location had a positive effect on collaboration. The introduction of new team members without lean experience resulted in waste due to the lack of adoption of the actual design method.

The mix of fixed price contract to Snohetta and pay by hour in Ramboll had positive effects. Architects focused on decision-making and efficiency and engineers feed resources to keep up with deadlines. The coordination within the team made an extensive utilisation of resources possible.

The design team had a focus on continuous improvement and learning from past experience, including regular assessment of on-going work and methods.

The project manager (PM) observed just minor cost deviation in the first package of tenders from contractors. This indicated that the deliverables of the design held the required quality. This was explained as a consequence of the use of lean methods. The design phase was going to be completed one month ahead of schedule. The PM has experienced that design is often more comprehensive than originally planned. The PM believes the process breakdown into time-restricted activities and focus on the flow in the detail design in the Academy project has contributed to a better product.

One major characteristic of the Academy was the intensive use of resources and knowledge in the design phase. This was expected and believed by the design team, to facilitate a more efficient construction phase with less errors and delays.

It proved impossible to obtain whether the lean process has resulted in a more effective construction phase and if it pays to invest in the design phase at the stage of our inquiry. Until now, the project has not undertaken any measurements regarding performance. The PM believes they have implemented lean in a right way so far. He considers they could probably have made more efforts to succeed, but that becomes a cost/benefit issue.

THE NEW NATIONAL MUSEUM OF ART, ARCHITECTURE AND DESIGN

The Museum project used Statsbygg's project execution model based on traditional project management models. The owner, the consultant engineer and the architect were located at a project office. The designers reported to Statsbygg every month. Originally they worked sequentially, but because of delays they started to work in two parallel plans to meet the project deadlines. The architects, Kleihues + Schuwerk as well as the consultant engineer, Ramboll had a paid-by-hour contract. The architects were organized in a hierarchy, with a few lead architects being responsible for general design. Their main working principle was to have all solutions ready before involving the engineers. The architects and the engineers stand as equal in the project.

The quality level of the planning was perceived to be high. The joint project team follows the main schedule and the functions and tasks of the different team members seem to be clear. To prevent misunderstanding, improve collaboration and encourage integrated solutions, a project office was established. This co-location was not regarded as a contributor to collaboration and value-in-use of the asset.

The architects as well as the engineers experienced that the personal relations within the project team were not optimal. They experienced a lack of an owner "decision maker" involved in the process, due to frequent situations where the design team was not able to get to consensus on an issue, but were still asked to solve it.

Statsbygg had an in-depth user survey in the front-end of the detailing phase, which required several modifications. This survey was initially scheduled to the initial phase, but due to formal problems the survey was postponed. The consequence was redesign in the detailing phase to align the solutions with user needs.

The available time frame for basic design was thought to be too limited. This resulted in what was regarded as superficial design, which in turn led to a need for an extensive rework and redesign in the detailing phase.

The consultant engineer experienced that the stakeholders in the project were not learning from experience and incidents earlier in the project**.** It was regarded as a general problem to provide the project with the required resources and competence, due to owner budget constraint as well as shortages in the project teams. From experience, in projects of this size, involved parties should have an organisational capability of at any time supporting the project with the required resources to ensure quality of deliverables as well as being within the time schedule.

DISCUSSION

The Academy project was characterised by clear distribution of responsibility, front-loading and focus on planning. This has resulted in flow in the process and quality of the design. The team members had the ability to make decisions in accordance with the requirements and keep up the project pace. As a result, the project kept up with deadlines, completed the design phase earlier than expected and was able to avoid delays. Visual planning, co-location and common BIM model contributed to transparency. This resulted in a common understanding of all stakeholder's objectives and superior collaboration.

In the Museum there were observed several conflicts between engineers and architects regarding design. The lack of a visible project governance and leadership was frequently mentioned as a problem. There was a general perception that more resources should have been deployed in the initial phases to avoid waste as a consequence of rework and redesign. In the Academy on the other hand, the stakeholders have been pleased with the amount of resources.

The Museum uses some of the same elements as in the Academy, such as having a project office. The collaboration in the Academy was perceived as very good, but not as good in the Museum. The lean approach and the collaboration to meet the project objectives appear to have given an improved process. The fact that the Museum was a lot larger and complicated project might be a source of error in the comparison.

The Museum and the Academy were both working on increasing productivity, with the idea that improved productivity would result in increased benefits for the client. The main driver of productivity was identified as early and good planning. Stakeholders in both projects were of the opinion that better planning and design should increase the performance – which in the end should deliver increased value. It seems that the Academy project to a greater extent has succeed at this.

Table 2: Advantages of the different approaches

Project	**Advantages**
Bergen Academy of Art and Design	1. Dividing the project into levels and sequence of work loads
	2. Good planning process, front-loading and high focus on the design phase in terms of available resources and time relative to project size
	3. Team spirit, good team work and collaboration
	4. The mix of fixed price contract and paid by the hour
	5. Clear responsibility distribution and with owner decision-maker
	6. Transparency, working in an common BIM model
	7. Focus on learning from mistakes and continuous improvement
The National Museum of Art, Architecture and Design	1. Measuring project performance
	2. No need for education and comprehension of the project execution model and the used terminology to new project participants

Lean in the Academy was considered to contribute to increased value creation through increased transparency, resulting in a better realization of the participants' primary objectives and better collaboration. Lean design has created value by increasing the probability of completing the project within time, cost and quality through better planning. Use of more resources in detail design reduces waste in the design and was believed to reduce waste under construction. The involvement of the users was as in the traditional approach. It is notable that there was no increased attention on value creation regarding total monitory value for the client – but mainly a waste reduction focus.

CONCLUSIONS AND FUTURE RESEARCH

It is hard to generalize the findings when the study is based on design approaches in only two projects. In this case lean design seems to have reduced waste in the Academy due to the focus on process, collaboration and planning. This is noticed as promising because it might increase in the consciousness around excellent processes and planning. The total value concept (as defined in this paper) was rarely considered. A reason for this might be that lean design was first introduced into the project in detail design. In future projects using lean design, there is a potential to have more focus on total value by implementing lean design from the very beginning and also consider to implement tools like TVD, CBA and SBD.

Further research in this context should focus on delivered value, ex-post assessment of use value and benefits. This may give a broader understanding of advantages and disadvantages of lean design vs. a traditional approach.

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APPLICATION OF PRODUCT DEVELOPMENT PROCESSES IN THE EARLY PHASES OF REAL ESTATE DEVELOPMENT: A FEASIBILITY STUDY

Christian Kron[1]

ABSTRACT

The standardization of processes in the construction and real estate industry is one of the basic requirements for a secure implementation of lean principles in practice. An important element for real estate development is to realize building projects efficiently and successfully. Among other things the task of a project developer is to organize, coordinate and control the interdisciplinary collaboration between internal and external stakeholders. The project developer has in consequence a special role by crosslinking the functional value chain processes in the real estate project.

This paper aims to provide an outline of a general approach to improve the quality of real estate development processes. By applying management methods of the product development processes (PDP) to the real estate development process, the possibility of errors should be reduced and interfaces should be optimized. The applicability of this product development processes in the early stages of real estate development will be demonstrated by way of example.

KEYWORDS

Process, product development, real estate development, kaizen

INTRODUCTION

The real estate development is a dynamic, time-limited process that begins with forming a concept and ends with selling of a completed and let real estate. In the early phases of real estate development strategic decisions are in the foreground, while in the later phases operational decisions are more important. But especially at the beginning of real estate development appropriate information are often missed to be able to decide whether a project is to pursue further or to quit (e.g. Schelkle, 2005).

Today there is hardly a company that has not implemented the successful elements of the Toyota Production System (TPS) (e.g. Koskela, 2001). The convincing results pioneer a transfer of these principles not only to the building construction but also to the real estate development. In this context, the question

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arises whether the real estate development is to be equated with product development of the manufacturing industry.

Unnecessary errors in the real estate development must be avoided. Starting with the project initiation, the errors proceed with a lack of demand analysis, faulty evaluation of economic efficiency, inadequate feasibility studies or not buildable constructions. This leads to unnecessary loops, rising development costs, delayed completion in real estate development and thus leading to a subsequent sale. The unpredictable duration of individual activities in the development process makes the synchronization of all activities and the elimination of waiting times difficult. Developments take place just in project form and thus are characterized in contrast to most processes in the manufacturing production with a degree of uniqueness. In addition, the complexity and the division of labor in an interdisciplinary real estate development process is added. On the other hand, developers work usually on multiple projects simultaneously and can fill waiting times in a project meaningful.

While the product and process design can be standardized for standard products, it is necessary to standardize the design and project controlling for non-standard products, such as real estate. In other words, it is necessary to map out standard methods for planning and management of real estate development (e.g. Ballard and Howell, 1998).

The aim of this paper should be to apply the product development process of the manufacturing industry with its methods to the real estate development process in order to reduce potential errors and to optimize interfaces. The process should be set up with the necessary project phases and participants.

PRODUCT DEVELOPMENT PROCESS

Product development is a series of activities that begins with the perception of market opportunities of a product and ends with the production, sale and delivery of this product (e.g. Ulrich and Eppinger, 2000). Smith and Morrow (1999) and Hale (1993) define the product development as a process in which an idea is created due to market and customer requirements in a product or technical system. In addition, the product development is usually a complex process, because of the scope of technical problems that must be controlled and also because of the diversity of stakeholders and organizational structures that are employed during the development of the product (e.g. Smith and Morrow, 1999).

The analysis of the product development process in research and practice began in the 60s with a formal approach of the NASA (e.g. Cooper, 1994). From the 80s first best-practice studies were published on success factors for product development, for example by Griffin (1997) and Cooper and Kleinschmidt (1998). After a long time predominant focus on cost reduction and restructuring efforts, the importance of product development grow in the 90s. A long-term survival of a company can only be secured through new products (e.g. Spath, Matt and Riedmiller, 1998). From the comparison of different definitions, a process can generally be understood as a logically connected sequence of activities which are limited by a defined input and output. The essential feature is that processes and activities are not isolated but connected to each other (Buchholz 1996). The advanced universal design theory of Grabowski and Lossack (1999) assumes that there is a universal product development process that is applicable to the interdisciplinary development of any products and thus also on real estate. A specific part includes all domain-specific extensions. An objective oriented product development is possible if all the requirements of different domains are defined completely and correctly (e.g. Grabowski and Lossack 1999).

Generic phase models have the goal to look at the product development process as general as possible regardless of industry or company specifics to allow a universal use. They are based on the hypothesis that common process structures exist (e.g. Brokemper and Gleich, 1999). A basic process model for the product development process comes from Cooper (1994). It is the so-called stage gate approach of the first generation. The second generation is a still in the industry commonly encountered model of a product development process. The features of this second generation are trans-sectoral phases and gates (marketing, production, sales, etc.), an increased focus on activities before the actual development process (feasibility studies, market studies, product definitions, etc.), increased market orientation and accurate decision points above the progress of the project with clear criteria.

REAL ESTATE DEVELOPMENT PROCESS

Concerning substantive description and conceptualization of real estate development process a number of models exist in the Anglo-American literature. Healey (1990) has systematized these models and has identified three basic approaches to the description of real estate development:

- equilibrium models
- agency models
- event-sequence models

Event-sequence models describe a pragmatic way to characterize the real estate development process. In general, there are descriptive models that divide the processes occurring in the real world of real estate development in individual idealized phases. Though they come quite close to the traditional flow charts of production and service processes in which the production of a product or the creation of a service takes place in several successive steps. At the beginning of the real estate development process are the three factors location, project idea and capital; in the end is the ready for use real estate (e.g. Bone-Winkel, 1994).

Event-sequence models are very well suited to capture the complexity and dynamics of the real estate development process. The development projects run through a "development pipeline" at varying speeds, depending on location, design factors and the capabilities or objectives of the project participants. In practice, the project schedule usually is represented by network plans. In the specific project procedure overlaps, parallel processes and feedback effects also appear.

The real estate development process includes all activities that are needed to develop a project from initiation to building completion and handover to use. The event-sequence model of the real estate development process by Bone-Winkel (1994) distinguishes five phases and is based on the phase model of the School for Advanced Urban Studies, University of Bristol (SAUS) (e.g. Barrett, et al., 1978). The goal-oriented strategy based real estate development process is divided into: project initiation, project conception, project substantiation, project management and project marketing (e.g. Bone-Winkel, 1994).

APPLICATION

REQUIREMENT

A scientific debate for process management in the real estate industry and especially in the real estate development was carried out inadequately or not at all, although the optimization of organization and processes, and thus the process management is becoming increasingly important (e.g. Held, 2010).

Significant improvements to the development process of real estate are only being achieved through a holistic approach to the conception, design and execution process. This applies particularly to the area of inter-company collaboration. The organization of cooperation by the client from plan to control up to executive functions, presents itself as a major challenge. The traditional real estate development has to be complemented by a standardized process management in which clear rules exist in the form of assigned tasks, competencies and responsibilities. This makes a reconfiguration of the conventional to an organizational structure necessary based on object orientated design. It requires a process-oriented organizational structure. The ability to cross-link the functional performance processes is already a competitive advantage that will enhance in future yet (e.g. Kaiser and Khodawani, 2008).

FEASIBILITY

The challenges in the development of real estate are versatile. To be mentioned in this context are the organization and coordination of interdisciplinary activities with internal and external stakeholders. In addition, controlling of the design process and managing approvals are important tasks. Looking at the product development of the manufacturing production, it has analogous requirements to a product development process as the real estate development and is faced with similar circumstances. Already in the conception and design phase a variety of stakeholders, such as project managers, architects, engineers and consultants have to be coordinated. Thus, the development process plays both in the manufacturing industry and in the construction and real estate industry a special role. Especially in the large and highly integrated networks of stakeholders in both areas, it is very important to realize optimization potentials and errors as early as possible in the process in order to avoid error propagation (e.g. Kaiser and Khodawani, 2008).

Still many real estate projects fail, because the related product development processes are not performed tight enough. Although various best practice studies show (e.g. Griffin, 1997): Successful companies have product development processes with decision points, called gates. Thus, according to a study by Cooper the existence of hard decision points on the resume or cancel of projects strongly correlate to the profitability of new product developments (e.g. Cooper, 1998).

Long-term studies of success factors in new product development draw a relatively homogeneous picture of what distinguishes successful companies. As shown by various benchmarking studies the existence of an excellent product development process is the most important factor of success (e.g., Griffin, 1997; Cooper, 1998). However, the sole mapping and modeling of this process is insufficient. Other success factors are associated with the company and product strategy, as well as a link to the tools of quality and project management. Among them is the existence of hard project break off criteria at each phase end (e.g. Cooper, 1998).

In order to create a process with higher productivity and a more reliable workflow, the Last Planner System™ is an appropriate production planning and control instrument that especially realizes the pull-principle in building and holding all project participants to active cooperation (e.g. Ballard, Hammond and Nickerson, 2009). The most important key element of the Last Planner System™ is the Last Planner meetings in which the Last Planners of different sections jointly plan the course, by making decisions and commitments. Therefore, the participants at the meetings must be skilled to make decisions and be empowered to be able to make decisions. Depending on the project phase monthly, weekly or daily meetings are held, in which commitments are analyzed and reasons for non-compliance with commitments are recorded. Elements of the Last Planner System™ could be cogitable for a more efficient design of the real estate development process.

REAL ESTATE DEVELOPMENT PROCESS MAPPING

Another method inside of Lean Construction for the continuous optimization of processes and thereby to increase project efficiency is the process-oriented assignment and execution management (AEM) (e.g., Kaiser and Khodawani, 2008). This method is following applied as a proposal for solution to the real estate development process.

A lean AEM systematic must meet clearly defined goals. The principal goal in this context can be mentioned is the improvement of stability and efficiency by mastering the complexity during real estate development. In order to realize this following sub-goals have to be achieved:

- Definition of standardized processes
- Clear assignment of tasks, competencies and responsibilities within the project organization
- Demand-supply of qualified resources and application of methods and tools in the project phases
- Composition of process-oriented team-organizations
- Use of a standardized reporting to measure process quality with short-term decision escalation

A basic principle within the AEM systematic to optimize product development is frontloading. Frontloading means to invest a lot more intensity of labor to identify optimization potentials in the early phases of the project to avoid a disproportionate use of staff resources in later phases of the project. In the early phases of real estate development it is possible through the use of optimization potentials to reduce costs disproportionately, as shown in Figure 1. A possible extension of the design phase is compensated by increasing design efficiency. Transferred to the real estate development, this means the provision and timely use of qualified resources and the application of the necessary processes and methods along the project execution. This produces always objective transparency according to project sequence and status in the project organization. In the early stages of a project development thus future planning and construction costs can be greatly affected. A user-oriented project development, in which any necessary specialists are involved at an early stage, can lead to considerable cost savings during the utilization phase. If the relevant professionals involved too late in the planning process, it requires frequent downstream planning changes when critical aspects have been forgotten (negative iteration). Also the testing of scenarios and alternatives regarding the economy and the needs-based planning is iterative. According to Ballard (2000) negative iteration, which is not an increase in value, should be avoided in the project development process.

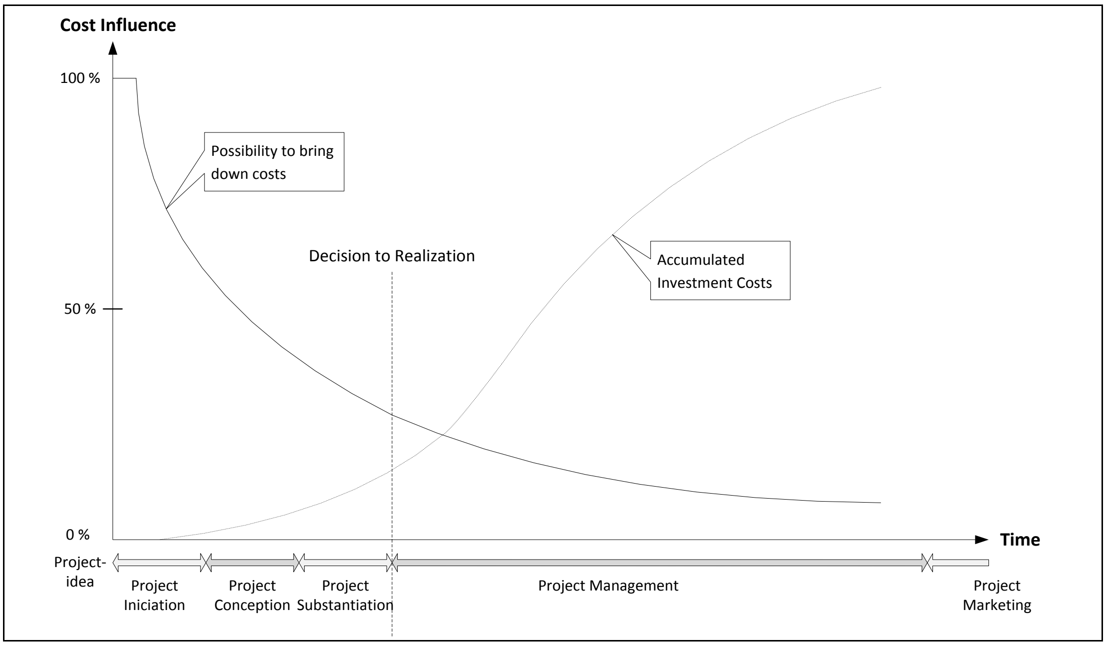

Figure 1: Qualitative illustration – Frontloading generates efficiency improvements throughout the real estate project development (Figure 3 in Kaiser and Khodawani, 2008)

The product development process (PDP) systematic from the manufacturing industry integrates the sum of all the activities that have to be performed for a successful start of production. The transfer of the PDP systematic on the real estate development is carried out in form of the AEM systematic with quality gate approach. This system consists of the following three tools:

- The process map, as a standardized and multi-stage process definition of the required activities, methods and tools along the real estate development,
- The interdisciplinary project teams with the necessary qualifications and defined tasks, competencies and responsibilities, which work through the process map and define the status of the project regularly,
- The standardized reporting system for showing transparently the project status in terms of quality, costs and schedules.

The process map, as shown in Figure 2, forms the basis of the systematic real estate development process. It is divided into three levels: project phases, quality gates and such as the so-called vertices. The project phases and quality gates form the basic structure for real estate development. By achieving a quality gate it is checked whether the required tasks of all project participants were processed and whether the objectives of quality, costs and schedules can be met. This ensures that the degree of maturity of the activities of all stakeholders is synchronized. Quality gates only may be passed if all the conditions are met for entry into the next phase. The required tasks of the project participants are more concrete along the real estate development process in the form of vertices. For each vertex the methods and tools are described. In order to ensure the application each vertex has a person in charge for execution and decrease.

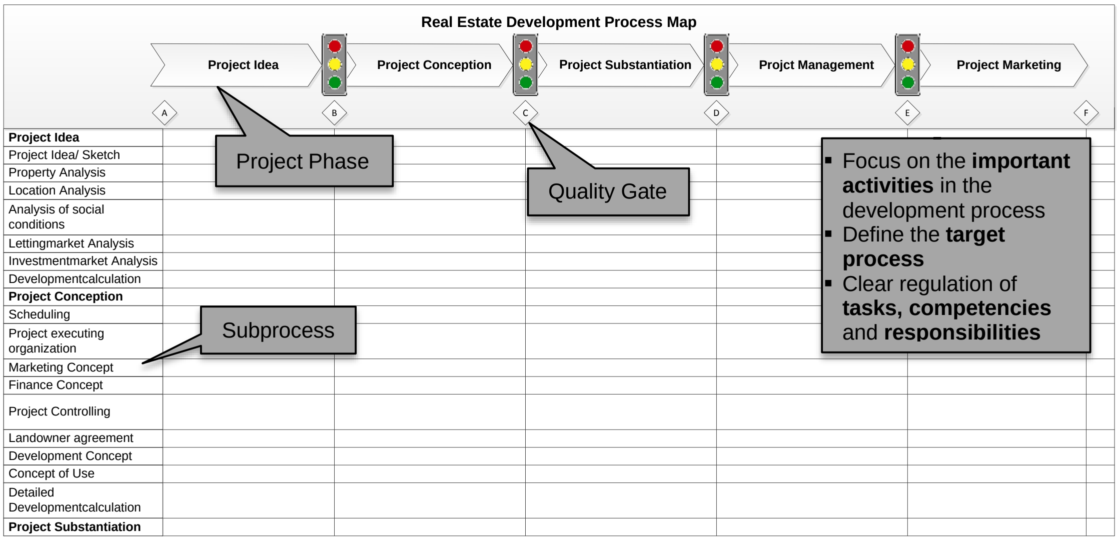

Figure 2: Example showing the structure of a process map

The process map is designed so that it is applicable in accordance with certain rules for each type of real estate development. Thus, the effort to create the process map is only necessary once and it can be used again depending on the project. Not be changed may the names of the vertices, the number and position as well as the phases of the project and the quality gates. The sum of all persons of charge for execution in the process map forms the interdisciplinary team, typically consisting of the following persons: Project developer/ project manager, architect/ engineers, users, finance/ banking, investors, contractors, government/ authorities and real estate services.

For each vertex of the process map a target date is planned by the project team at the beginning of the project. The project team is responsible for regularly reviewing the project status with respect to the faultless delivery, if necessary taking special measures and lastly to report project status. For this purpose the AEM systematic provides special tools. First: from the process map directly derived AEM checklist in which all vertices from the process map are evaluated. Second: the management summary that compactly summarizes the overall status of the project including the indication of deviation causes and countermeasures. All instruments are fully connected to the process map that is to say the use of the defined standard process is automatically ensured.

A major challenge in the real estate development is the ever-changing and decentralized project organization. As a result, the use of modern means of communication is required within the project teams. Multimedia team meetings are held. Efficient team meetings will be realized, for example via conference enabled phones and a common view of the tools. Reporting is generated directly from the weekly meetings of the project team and therefore requires no additional effort. The project status by using a traffic light rating is reduced to answer the essential question: "Will the next milestone be held in compliance with the quality, costs and schedules from the perspective of the project team?“ Can the project team under its own power no longer ensure the achievement of a milestone, the switch over to a red light on a decision memo (incl. solution alternatives and recommended of the team) escalates the problem. This procedure ensures that the status of a project is updated with each team meeting and corresponds to the consensus opinion.

The standardization of the real estate development process on the process map enables further continuous improvement of the AEM. Great potential is in the case of any problem in the question of the project management to the project team: "How can we ensure the process that this error does not occur again?" In this way in purpose of error prevention the process map should be constantly improved by any error over all projects.

RESULTS

Clear overview of the processes in real estate development and project organization

By using the AEM systematic the entire real estate development process is known with its complex interfaces, and generates a holistic understanding of the process. The project participants communicate regularly and have clarity on assigned tasks, competencies and responsibilities. The resources in the various phases of the project are clearly defined by lack of capacity and qualification. Resource constraints are obvious. The improved transparency leads to much smoother and more stable project collaboration.

Increased responsiveness through early detection of deviations

Weaknesses and errors can be detected early by the interdisciplinary team. Solutions will be immediately developed by the project teams. At the same time knowledge across divisions is used and exchanged.

Objective Project Status Review - errors are seen as opportunities for improvement

The degree of maturity of the project is clearly defined by the quality gates and gives everyone involved a common understanding of the current status. By the joint review in the team honesty is promoted in the project organization. An important finding is that the award of red lights should not be sanctioned. Incentives must be created to establish an open error culture. The clear escalation barriers and rules demand focused decisions on all hierarchy levels.

Improved internal project discipline and cooperation

The processes involved in team meetings, for example, Participation rate and the use of standards is measured. This leads to improved discipline in preparation and cooperation.

LIMITATIONS

The described process model has its limitations in the areas that cannot affect the project developers as a management person in charge, such as increasing creativity and problem-solving skills of project participants. The wrong use and dislocation of participants can be avoided by assigning the skills in the process. At least an unobstructed authorization may be granted by the definition of the output requirements for the quality gates.

CONCLUSION

The transfer of lean principles to the real estate development supports the continuous improvement of effectiveness and efficiency. At the same time a uniform orientation option, alignment and language of the project stakeholders is established. The implementation of lean principles is done on best practices, which are first tailor-made and then sustainably introduced for the company. The existence of a good real estate development process is an important success factor. However, the sole mapping of the real estate development process is not enough. The modeling of real estate development processes by Event-Sequence models and process chains makes an important contribution to increasing the tor the process chain "from Market to product" shows that there is a basic procedure by which - regardless of the project - real estate can successfully be placed on the market. By extension, these models can be adapted to the requirements of different domains. However, it is important that process models are combined with a project management that considers the specifics of the project. In each project the activities have to be planned targeted and subjected to regular controlling. Therefore at the end of each phase a project continuation decision should be made by oriented towards the goals of the project management.

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CONTRACT MODELS AND COMPENSATION FORMATS IN THE DESIGN PROCESS

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ABSTRACT

This paper presents the most common contract models and compensation formats for the design process, and considers to what extent they give the designers the best opportunity to maximize value for the customer and minimizing waste in the design process.

The presented results are based on literature review combined with a study of documentation and interviews with key personnel, into Norwegian projects.

Findings show that lump sum and cost reimbursement are the most commonly used compensation formats for design. The most commonly used contract models are Prime Contract and Multi-Party Contract. From the case studies, it emerges that the designers' challenges do not lie in the contract model itself, but rather in whom they respond to – the client or the contractor. The paper further finds design-bid-build combined with cost reimbursement to be most favourable in the early iterative stages, where the scope is poorly defined and/or characterized by a flow of new information. The design-build contract combined with lump sum is more favourable in later sequential stages, when the scope is well defined. However, if the process is still characterized with constantly new information, cost reimbursement are highly recommended.

KEYWORDS

Contract, contract models, compensation formats, design management, lean design.

INTRODUCTION

The Architecture, Engineering and Construction industry (AEC) has a potential to increase its productivity and the value of the project. Traditional construction projects are executed with fragmented organization and contracts that hinders collaboration between participants. New procurement models and contract strategies need to be developed to meet these challenges. Creating an appropriate procurement model is an

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important task for a client to consider as it establishes the basic rules of the game and determine the execution as well as the result of a project (Toolanen and Olofsson, 2006; Lædre, 2006). According to El. Reifi and Emmitt (2013), different procurement models may cause inefficiencies in the early design phase, in terms of delays, budget overspends and, in many cases, less value being delivered to the client.

In order to address such challenges, the literature typically recommends approaches as Lean Project Delivery System, which encourage relational contracting and involvement of all key participants early in the project (Ballard, 2000a). Integrated Project Delivery (IPD) is a relational contract that is conceived to accommodate the intense collaboration required in complex building projects (Thomsen, et al., 2009). However, the use of IPD demands that the owner select team based on best value rather than on the lowest bid (Ghassemi and Becerik-Gerber, 2011). Actually, a competitive tendering process is best avoided in order to preserve the accumulated knowledge (Zimina, Ballard and Pasquire, 2012). In practise, such approaches prove difficult to apply. On public projects that include public founding, a competitive tendering process may be required by the public contract regulations. All countries that are members of World Trade Organization have to follow the Agreement on Government Procurement (GPA). In Norway, this specifically states that all public contracts shall undergo an open competitive tendering process that secure transparency and fairness in the process. Consequently, the industry is still favouring a traditional fragmented contract strategy, both in public and private sector (Lædre, 2006).

Through our study of the literature, we have not found many that discuss the influence of contract models and compensation format for design in projects using lean construction approaches. Through investigation of two major public Norwegian Hospital project, this paper addresses this knowledge gap. The research questions are:

- What are the most common contract models and compensation formats for the design process in Norway?
- To what extent do these facilitate the iterative and sequential design process?
- Which contract models and compensation formats give the designers the best opportunity to maximize value for the customer and minimizing waste in the design process?

Value is a complex subject in lean construction context, but the authors of this paper will use value to describe a good or a service that meets the customer’s need at a specific price at a specific time (Womack and Jones, 1996).

RESEARCH METHODOLOGY

The research was carried out by a literature review in accordance with the procedures described by Bloomberg, Cooper and Schindler (2011) and investigation of two cases, according to the prescriptions of Yin (2009). This was carried out using a study of documentation and semi-structured interviews with key personnel. It was not possible to conduct an observational study as the designing in both cases was finished.

The literature review focused on contract models, compensation formats, design process, reducing waste and increasing value in the design process. Literature has been collected from research databases (Scopus, Compendex, IGLC Conference Papers and google scholar), library databases as well as from references of reviewed articles. In addition, literature on the building process, lean design management and dependencies between tasks was reviewed.

Two cases were chosen to study, notably: two major Norwegian hospital projects: St. Olav Hospital construction phase 2 (will further be referred to as St. Olav Hospital) and New Østfold Hospital. The projects are resent, allowing the informants to remember the project well and be able to contribute valid data. Equally, the projects are similar in type yet carried out with different contract models and compensation formats in the different phases of the project. St. Olav Hospital started in 2005 and ended in 2009. It consisted of several buildings, 85.000 m^2 in total. New Østfold Hospital started in 2011, and is expected to be finished November 2015. The Hospital consists of one building, accounting to 85.500 m^2. In total, eleven interviews were carried out with five designers/engineers, four contractors, and two representatives from the owner organization. An interview-guide was used to ensure reliable and comparable data. The procedure enabled the interviewer to pursue interesting answers or unexpected themes that could appear during the interview. In order to obtain comparable data, all of the interviewees were posed the same questions.

The documentation studied consisted of documents received from the informants, and were mainly organization maps, schedule plans, presentations of the projects and preliminary reports. The documentation review provided details that corroborated information from the interviewees (Yin, 2009).

The use of IPD as recommended in the Lean literature is not commonly used within Norwegian construction industry. Therefore, we limit the contract models to design-build (DB), and design-bid-build (DBB). We do not consider the organization of these cases, but to what extent they facilitate for the iterative and sequential design process. Standard rules and regulation for contract models in Norway present two of the most important standard contracts for assignment between a builder/client and consultant/designer, NS8401 (Standard Norge, 2010a) and NS8402 (Standard Norge, 2010b). These provide guidelines for the use of lump sum and cost reimbursement, and occur in each end of the distribution of responsibility and risk. Therefore, we limit the compensation format to these extremes. Theoretically, both of the contract types and compensation format can be combined with each other. However, in this study we limit to the combination DBB with cost reimbursement and vice versa DB with lump sum, according to the combinations of the case studies. The study is seen from the designer's point of view, and the conclusion emphasizes value seen from the client's perspective.

THEORETICAL FRAMEWORK

THE DESIGN PROCESS

Lean thinking can be summarized in five principles according to Womack and Jones (1996), 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. What creates value in design is a complex question. It will be a result of the conversation between the ends, means, and constraints of the client (Ballard, 2008). Unlike production, where rework is inherently negative and wasteful, iterations can be both positive and negative in the design phase (Ballard, 2000b).

Allowing the iterative processes to run as long as necessary can be beneficial to the value of the project. If they run too long, however, they can have serious implication on the project, concerning time and cost (Knotten, et al., 2015).

The design phase will typically start with a high degree of complexity and interdependency between the different tasks as the design team is looking for better solutions to the problem. As the problems get solved, the complexity of the project decreases and consists mostly of sequential tasks like delivering drawings and descriptions. The process can therefore be seen as a highly iterative and creative in the early phase of design, and more sequential later when most of the decisions are already taken (Knotten, et al., 2015).

The MacLeamy curve, in Figure 1, shows us how uncertainty in a building project decreases over time as the level of information increases. Research has highlighted the importance of the early design phases in helping to reduce uncertainty and improve quality (Samset, 2008; El.Reifi and Emmit, 2013). The cost of making changes and modifications in the later phases of the project increases considerably versus doing this in the front-end phase of the project. Samset (2008) argues that sufficient time for planning and designing is essential to prevent late changes for the design team. In order to reduce uncertainty and prevent changes and variation orders late in the process, he proposes three actions: collecting information early in the project, doing a proper design job, and coordination between disciplines to prevent collisions, errors and erroneous assumptions.

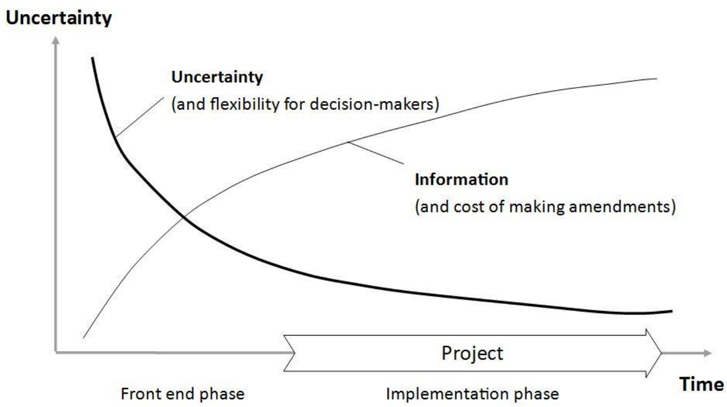

Figure 1: Uncertainty and information in projects over time (Samset, 2008).

There are many ways to divide the building process into phases to create an overview and control over critical stages. An example of division into phases is RIBA (2013), who breaks the process down to eight phases: Preparation & Brief, Concept Design, Design Development and Technical Design, Construction, Handover and Close Out & In Use. For the case of simplicity, the authors of this paper choose to consider the building process as twofold with front-end phase and implementation phase. The front-end phase represent the iterative phases, and the implementation phase the later sequential phases.

CONTRACT MODELS IN NORWAY

When a client chooses how to carry out a project, he can choose design-bid-build (DBB) and manage the design team himself, or he can choose design-build (DB). In the former, the client is responsible for the design team, and in the latter, he makes the contractor responsible for the design team (Toolanen and Olofsson, 2006). In addition, the client may choose untraditional contracts for his project, e.g. IPD.

There are several advantages and disadvantages for the client to consider, standing before the selection of contract model. Choosing DB may cause cheap solutions, as the contractor wants to save money (Lædre, 2006). This could further lead to solutions that are not optimal in a life-cycle cost evaluation, and may have negative consequences for the clients operation costs (Grimsmo, 2010). On the other hand, the contractor has a better basis to focus on building solutions (Lædre, 2006). The contractors have valuable information about technical products, solutions and materials that is advantageous to include in the front-end phases, and will benefit the client as the constructability will improve (Sødal, et al., 2014).

Whether it is the client or the contractor to contract the designers, there are several contract types to choose from. Two frequently used models when contracting designers in Norway are so called Prime Contract (totalprosjektering) and Multi-Party Contract (gruppeavtale). In the Prime Contract, the client writes a contract with one designer who becomes responsible for all design-work. The prime designer may enter into contracts himself to complement expertise or increase recourses to carry out the commission. The Multi-Party Contract is a jointly responsible group of several designers that have signed a mutual contract with the owner, as well as an internal contract between themselves.

COMPENSATION FORMATS FOR DESIGN IN NORWAY

Lump sum

Lump sum reward the designers according to the result of their work. For the client/contractor, this permit predictable costs and reduces the risk of cost overruns related to the design work. It is a good choice if the client/contractor project a very high level of available information, and desires a low level of design control effort (CII, 2003). According to Eikeland (2001), the designers will be motivated to be efficient to increase their winnings. It is desirable for the designers to produce the agreed product with the least possible use of resources to satisfy the minimum requirements of the product. The focus on reducing time and cost could provide erroneous focus in the design process, and the designer may end up discarding good solutions for the project as a whole.

Cost reimbursement

Cost reimbursement reward the designers based on actual time taken to perform the assignment. It requires low level of available information at award of design contract, and high level of client’s design budget risk and design control effort (CII, 2003). The contract is better than average for allowing changes during design and the client can be involved in critical aspects of design (CII, 2003). Cost reimbursement is a good choice for commissions with weakly defined scope and where the designers’ work is poorly described (Lædre, 2006). Unlike lump sum, cost reimbursement will motivate the designers to provide high efforts, as it provides a higher profit (Eikeland, 2001). This is positive in relation to the quality of the product, but negative in the sense that the designers may become inefficient.

FINDINGS AND DISCUSSION

THE MOST COMMON CONTRACT MODELS AND COMPENSATION FORMATS FOR THE DESIGN PROCESS IN NORWAY

Contract models

In St. Olav Hospital, the client chose to contract the designers on a Multi-Party Contract in the front-end phase. The design group consisted of several designers in a jointly responsible group that signed a mutual contract with the client. Later, in the implementation phase, the client established four DB-contracts. This resulted in fragmentation of the design team, as the client split the group in four and delegated them to each contractor. In New Østfold Hospital, the client chose to manage the whole project himself, which included approximately 50 contracts with designers, contractors and suppliers. The client chose to contract the designers on a Prime Contract through the whole project, and thereby made them responsible for all design-work. Findings indicate that Prime Contract and Multi-Party Contract are the most commonly used contract models in Norway. Interestingly, findings show that the designers were unable to tell the difference between advantages and disadvantages in these contracts. The interviewees argue that the challenges lies in to whom the designers should respond to – the client or the contractor. The further findings will therefore explain the advantages and disadvantages between the DB and DBB, in order to ensure a facilitated design process and value for the customer.

Compensation formats

In both studied cases, the client chose to contract the design team on cost reimbursement in the front-end phase. Additionally, in St. Olav Hospital, they chose to supplement it with a bonus as incentive to prevent inefficiency that the compensation format may cause. The bonus depended on satisfactory work within milestones and budget. Thereafter, when entering the implementation phase, the two clients made different choices regarding the compensation formats for the design team. In New Østfold Hospital, the client chose to continue with cost reimbursement throughout the whole project. In contrast, the client in St. Olav Hospital changed it to lump sum after delegating the designers to the contractors.

During the interviews the informants explained that cost reimbursement is a preferred choice in the front-end phase, as it mainly are others than the designers who define the process and the environment they contribute in. The scope is generally weakly defined, and the process is iterative as the client constantly make changes in the planned solution, and the designers have restricted possibility to influence their time consumption. In contrast, lump sum seems to be a more reasonable choice in the implementation phase, where the scope usually are well defined, and the process is sequential.

TO WHAT EXTENT DO CONTRACT MODELS AND COMPENSATION FORMAT FACILITATE FOR THE ITERATIVE AND SEQUENTIAL DESIGN PROCESS?

According to the literature, the implementation phase normally contains sequential tasks for the design team. It is conceivable that this is true for processes where construction and design are sequential phases. However, in both cases in this study, the construction process and design process were parallel processes. The interviewees argue that the contractor's economical focus, late contracting of suppliers, and late involvement of the users, created a process characterized by constantly new information requiring changes and modifications to the planned solution. Hence, the implementation phase contained iterative tasks for the design team. However, the iterative design process was not taken into account when planning the schedule of the implementation phase, and created an unfortunate situation for the design team. According to the designers, the schedule facilitated the sequential activities at the construction site. Consequently, they did not get enough time to communicate and coordinate within the design team, which they further argue, increased the likelihood of waste and reduced value for the client.

Contract models

In DB, the contractor controls who the designers are allowed to communicate with. The interviewed designers express that they lose contact with others in the project, as the contractor dissociate them from discussions with the client. The designers state that it is a disadvantage for collecting information and for the collaboration between project members. Similarly, these disadvantages may occur due to the contractor's schedule, according to the designers. The schedule is primarily adapted for production, and fails to facilitate the design process. The designers argue that the lack of facilitation entails risk in terms of poor collaboration, coordination and quality. The designers do not get enough time to gather information and check things that are necessary to perform their work. This may cause the designers making assumptions that may prove to be incorrect and thus lead to changes and iterations in later phases. This may further lead to unnecessary costs to the project. Given the lack of focus on maintenance and operational consideration, the client risks not getting the quality that he wants.

On the other hand, the contractor's possessions of the best and latest knowledge of construction methods give the designers unique opportunities to take into account information much earlier in the process. As a result, the uncertainty in the project may reduce and less assumption are necessary to be taken. This could lead to lower costs, as less modifications in the design are necessary, and hence fewer iterations are needed.

The designers state that they gain better opportunity to collect needed information to perform their tasks when responding to the client in a DBB-contract. The designers may have direct contact with the other participants in the project, which form good guidelines for the information flow in the design process. The interviewees also claim that it is easier for them to affect the schedule in a DBB-contract, which grant them good opportunities to plan their own work.

Compensation formats

When the designers give an offer on a lump sum contract, it is difficult to anticipate delays and deliveries of necessary documentation so early in the process. Therefore they must base the assignment on an ideal process. Consequently, in order to deliver in time and earn money on the assignment, it causes them making assumptions, and producing a product that only satisfies the minimal requirements.

The designers explain that the contracts strict schedule makes the designers little motivated for interaction. They are likely to get cynical about meeting, more focused on their own discipline, less flexible to look at other opportunities, and no one wants to take the responsibility for the interfaces. The lack of focus on the totality may be at the expense of good solutions. In addition, it becomes very important for the designers to avoid performing tasks that are not included in the contract, as they risk not being paid for it. These tasks typically concerns interfaces. This results in a strict regime of variation orders. The designers must notify every time they believe that the task fall outside the contract to ensure being paid for the work.

Findings clearly show that lump sum create poor facilitation for the design process, as the designers focus against schedules and costs rather than collaborative working methods and the product as a whole. In addition to the client's value, the contractor's value may be at risk as the designers produces less, poor and incomplete drawings when they have reached their contract price.

In St. Olav Hospital, the client chose to contract the designers on a lump sum contract in the implementation phase. To ensure a well-coordinated process, the client introduced a collaborative phase with both the contractor and the designer. The client wanted to clarify the building and the deliveries with all parties, to make sure they understood the assignment. This enabled the contractor to influence and adjust the product, and thereby made the implementation phase less uncertain and more predictable for the designer. However, according to the interviewees, the design process still contained iterative tasks as new information and changes in the planned solution still occurred. As a result, the client were unable to get rid of the disadvantages related to the lump sum.

Unlike lump sum, cost reimbursement create a good basis for collaborative working methods, and ensures good quality, according the interviewees. To reduce their uncertainty and increase their profit, using enough hours to ensure a good and valuable product is essential. The designers request more information instead of making assumptions, which may lead to fewer changes, modifications, and iterations in the later phases. They focus on the interface between the disciplines and perform good quality assurance. According to the interviewees, this compensation format makes the best guidelines for facilitating the iterative design process.

The disadvantage with cost reimbursement is the risk of abuse of the contract, as the designers may work inefficiently to secure more hours spent on the project. This could further provide a more expensive product for the owner. In St. Olav Hospital, the client tried to avoid this by giving the designers an incentive. The result of this was successful. The designers managed to stay within budget, thereby preventing the downside the compensation format may entail.

CONCLUSION

This paper is limited to consider compensation format and contract models in the design process. The investigated cases have used cost reimbursement and lump sum as compensation format. Of contract types for design, the cases have used Prime Contract and Multi-party contract. Further, considering the facilitation of the design process, it emerges that the most important main distinction in contract models are between DB and DBB. In the two investigated case studies it appear that the compensation format is more crucial than the contract model to ensure value for the client.

For the iterative front-end phase, the interviewees argue that DBB complemented with cost reimbursement, is the most appropriate to use, ensuring a good design process and value to the client. At the same time, the interviewees state that DB appear to be the best to facilitate the implementation phase, as the contractor may serve the design team with valuable information earlier in the process. The literature shows that the implementation phase have less uncertainty, making the lump sum a good choice, as shown in the theoretical situation in Figure 2a. This would provide value for the client in terms of effective production keeping the budget and schedule in focus.

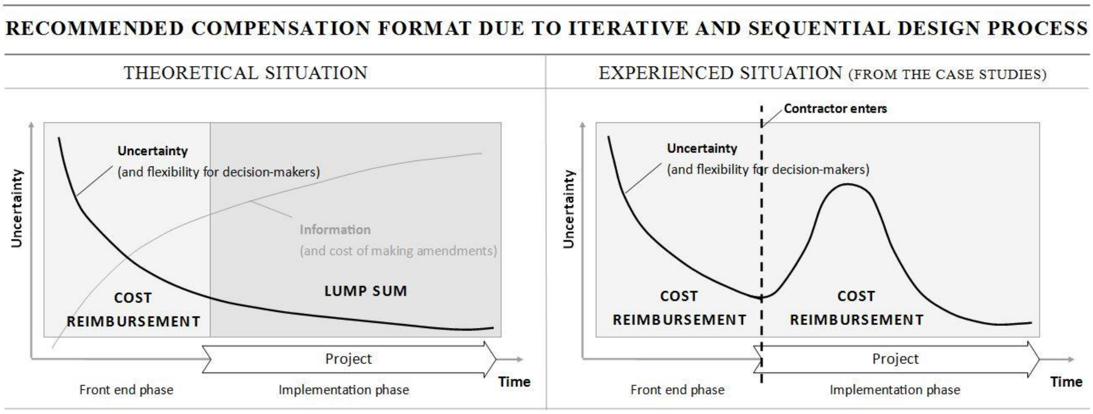

Figure 2 a and b: Theoretical situation based on Samset, 2008. Experienced situation based on qualitative, empirical data.

However, the case study shows that changes and constantly new information still characterizes the process, as shown in the experienced situation in figure 2b. This paper argues that cost reimbursement is the most appropriate compensation format to use, as it gives the designers the ability to manage the iterative design process and create value for the client.

In sum, the answer to what is the best choice of contract model and compensation format to maximize value for the client and minimize waste in the design process, depends on the project type.

The result is more appropriate to the case studies than to the context. Different project contexts and indeed diverse types of projects and clients would suit diverse types of contract and compensation modes. It is very hard to justify the generalisation being presented based on two Norwegian cases only. However, the result could be useful for those who are contracting designers to their construction projects.

We have covered a part of the knowledge gap, but for further work, we recommend to look at the limitation of this paper and expand the research to include more compensation formats and contract types, e.g. partnering and IPD. We also recommend to look closer at project organization due to contract models and expand the research to include more cases in order to include quantitative data.

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ETHICS OF THE DESIGN PHASE – A DESCRIPTIVE APPROACH

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ABSTRACT

This paper reports on a pilot study on the design phase in Norwegian construction projects using elements from lean construction approaches. The ambition has been to establish a descriptive picture of ethical challenges in the design phase in general, and of projects characterized by lean design in particular. In addition to a literature review and a document study, interviews with key participants were carried out according to a qualitative approach. The study was undertaken in order to address both general questions of ethics in construction project management, and more specific questions pertaining to the design phase of such projects. This research finds indications of actors manoeuvring in the design phase for own benefit at the expense of other actors. The findings indicate that the design phase poses significant challenges in light of tender documents pricing and exploiting cost reimbursement contracts. In some of the projects examined, participants were found to shift loyalty after transfer of contracts and they actively tried to steer the decision processes in their own favour. There does in fact seem to be a room of manoeuvre between what is unlawful and what is ethically sound in this phase.

KEYWORDS

Ethics, design, lean design, hidden agendas, trust.

INTRODUCTION

This paper intends to outline an understanding of ethics in the design phase as part of a more general enquiry within the field of the ethics of the Norwegian AEC (Architecture, Engineering and Construction) industry. The importance of increasing the awareness among practitioners, however, seems crucial to attaining what Mirsky and Schaufelberger (2014) maintain as the most important topic to the future of the AEC industry, notably "honourable, professional practice" (Mirsky and Schaufelberger, 2014 :vi). More recently the industry have witnessed an increasing interest in the field of applied ethics in general and in professional ethics in particular

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(Christoffersen, 2010). Different professions establish rules and regulations, such as medical doctors, teachers, social workers etc., and the number of publications is ever increasing. The authors of this paper have so far not seen this trend reflected strongly in publications concerning the AEC industry in general, or in actual industry agreements in Norway. Notable exceptions from this general statement include the writings of (Ray, et al., 1999; Fellows Liu and Storey, 2004; Collier, 2005; Bown, et al., 2007; Bröchner, 2009; ; Corvellec and Macheridis, 2010; Hill, et al., 2013).

Considering that the AEC industry in general and in Norway in particular typically receives attention as an industry of doubtful virtue, 1) where neither the police, the tax authorities nor the professional organisations fully master the challenges posed by professional practice (Andersen, Eldring and Roed Steen, 2014), 2) where the inherent complexity in itself opens the opportunity for suspicious dealings (Gunduz and Önder, 2012), 3) where fraudulent business practices undermine the reputation of the industry (Slettebøe, et al., 2003) and 4) that lacks a clear vision based on a fortified ethical foundation (Wolstenholme, et al., 2009), we find this strange. As Hill, et al. (2013) comments, there is probably no simple solution, no “quick fix”, to the challenges of ethical nature that the industry face. Tackling such challenges necessitates, it seems, both insight and endeavour. We believe this proves especially true when considering the design phase of construction projects.

In this paper, we analyse ethical challenges in the design phase for the construction industry from a structural perspective. The underlying idea is that the manner in which the industry is organised and certain inherent characteristics form specific challenges of an ethical nature. Rather than presenting any clear (normative) framework of what is good and bad behaviour, we intend to outline the challenges posed in a descriptive manner. In other words: our ambition is to present certain elements pertaining to how industry practitioners judge practices with which they are familiar. The research questions we intend to address are:

1) What challenges of an ethical nature are commonly encountered in the design management phase of construction projects?
2) What are the structural (systemic) reasons for such challenges appearing?

Figure 1 illustrates a simplified categorisation of different behaviours, depending on whether they are lawful and ethical. It also illustrate that the distinction between behaviour perceived as ethical and behaviour perceived as unethical is not always clear-cut. If the behaviour is lawful and perceived as ethical, nothing is wrong. If the behaviour is not lawful, then it is clear that something is wrong. Our research is limited to lawful behaviours perceived as unethical, because this is where we expect to find the challenges of ethical nature.

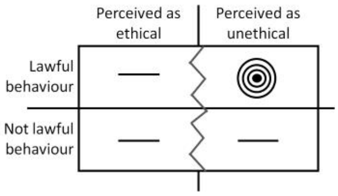

Figure 1: Extension of the law and ethical behavior, where this paper concentrates on lawful behavior perceived as unethical.

METHOD

The analysis presented in this paper is mainly based on interviews with actors with considerable experience from construction projects, in line with the recommendations of Yin (2014) – notably with key actors in four different Norwegian AEC-firms (a consultant firm and three contractors). In addition, a literature review of general literature on the subject of the design phase and ethics in construction management has been carried out in accordance with the procedures described by Bloomberg (2011). The initial academic footwork of the research presented here was carried out by two master students of project management analysing two case studies, particularly chosen on basis of their understanding of the field and personal initiative. Their interest in design management was of a generic nature – a sub-set of questions posed during the interviews addressed the concerned ethical aspects. Interestingly, these first interviews did not yield significant results – the students found the respondents to be unwilling to comment on the questions concerning ethics. Consequently, a more personal approach was chosen, where two of the authors of this paper contacted colleagues with whom they shared professional background. This approach proved largely more fruitful, even though the value-laden questions necessitated a certain period of convincing before the interviewees revealed pertinent information.

Semi-structured interviews with 14 professionals were carried out – four in group interviews, ten individually – with contractors and advisors in the construction industry having a broad experience in project based endeavours. All interviewees have played key roles in project execution teams. The interviews were open and flexible enough to include the possibility to encompass interesting observations.

All interviewed in this study were consultants or design managers, participating (or formerly participated) in projects using lean construction. The material presented constitutes a pilot study to the study of unethical behaviour in design. 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

In order to understand properly what is involved, a scrutiny of the concepts of ethics and design management respectively imposes itself. This scrutiny includes differentiating ethics and the law; normative and descriptive ethics; individual and socially oriented ethics; and the implications such delimitations will have for the study of the design process of construction projects.

ETHICS

Though often concurrent with, ethics must be separated from the field of the law in order to be fully understood. What is perceived as unethical can – in certain circumstances – be lawful, whilst what is perceived as ethically laudable can be deemed unlawful.

Ethics can be separated into normative and descriptive ethics. The first of these profess judgments concerning the manner of acting in the world. This is ethics as most have encountered it, the lessons promulgated being from different traditions such as deontology (Kant etc.), consequentialism (Mills etc.), virtue ethics (typically in the tradition from Aristotle) or various contemporary approaches (Habermas, Sartre, Lévinas , Foucault etc.). Analyses of this sort seem in fact – more or less consciously – to reveal how little that has been done of ethical analysis within the project management literature. See for instance Helgadóttir (2008) for an example of an analysis inspired by Aristotelianism. Descriptive ethics, on the other hand, typically analyses the judgments of behaviour in the world according to the vocabulary of ethics. Rather than developing a framework for judging the appropriateness of actions, such analyses typically investigate the reasons underlying such judgements in specific contexts. In this paper, we proceed according to a fully descriptive analysis.

Depending on which analytic level the analysis is situated, it is possible to distinguish individually oriented and social ethics (Ray, et al., 1999). The first of these concerns the individual as moral actor, whilst the latter concerns the ethical qualities of social systems. The intention of this paper is not to carry out any sort of blame game on a personal level. What occupies us here is rather judgments of interviewees as representatives of a group, that is, as professionals within the AEC industry analysing it as a social system.

In order to address questions as the above posed, with the limitations more or less explicitly outlined here, we base our analysis on Taylor (2004), who has developed the idea of a so-called social imaginary. The term denotes the common perceptions of what is acceptable behaviour and not within a certain social community. Such perceptions and opinions are often not properly articulated and therefore transmitted from individual to individual as “silent knowledge”. The central point of Taylor’s argument is that individual actions in the world – that is, why we act as we do – can be made understandable in light of a narrative explaining the function of these individuals within a greater whole. The analysis of such social imaginaries can thus help the analyst to understand why actors act as they do, and why certain actions are judged condemnable whilst others are judged laudable by the actors themselves. Applied on the AEC industry, it does, in effect, provide a tool for comprehending the judgements of professionals towards specific practices.

Taylor is not entirely unique in this undertaking, a fact he himself acknowledges. The concept of a social imaginary correspond to some degree to what Wittgenstein calls “background” or what Gadamer calls a “horizon of understanding” – for a discussion of these thinkers, see Dreyfus (1991) and Searle (1995). The appeal of the concept of Taylor – and which distinguishes it at least to some extent from these other conceptions – is the underlining of the social nature of this imaginary. To our purpose it is exactly this social anchorage we are seeking; notably, we want to examine how certain practices occur and are judged within a social relationship such as that of the AEC industry.

According to the literature study carried out in the research process leading up to this paper, neither ethical frameworks nor juridical ordinances suffice for understanding the challenges the actors of the industry face. By nature, such frameworks or ordinances enter the scene post-conflict. In the following pages we intend to carry out a descriptive analysis of the design management and specific challenges posed in the design phase.

DESIGN MANAGEMENT

The design processes constitute a key linkage point between the expressed needs of the client and the actual realization of the construction project. Not surprisingly, this is a phase where priorities predictably clash, most notably where actors can be suspected to follow their own agendas rather than the general project objectives. Understanding the nature of the challenges involved in this phase constitute a necessary step in the progress towards the development of measures against unethical behaviour. In the following, we therefore outline some of the features found to be the most influential to the understanding of the design phase in contemporary literature, before summarizing the implications of these for the field of ethics in the design phase.

Eikeland (2000) tend to divide the building process into three sub-processes; brief process, design process and the production process. Riba (2013) divides the building process further down to seven phases; Preparation & Brief, Concept Design, Design Development, Technical Design, Construction, Handover and Close Out and In Use. Although these models are usually shown as a linear sequential stage models, Eikeland (2000) points out that the brief-, design- and construction process in practice function more in parallel and overlap than what can be expressed by such a sequential representation.

The building design process consists of pooled, sequential, reciprocal and intensive dependencies between tasks (Thompson, 1967; Bell and Kozlowski, 2002). A standard project management approach (e.g. Pinto, 2013; PMI, 2013) are suited to manage the pooled and sequential dependencies, whilst the reciprocal dependencies can be challenging to manage with such approaches. However, it is important that the design manager knows that the different interdependencies will vary throughout the design phase and sometimes the design phase consists of all four types. Consequently, making the design phase complex to manage as different tools and methods might not be capable of handling them all simultaneously. By identifying the different interdependencies, the manager can use the right tools to improve the design team performance (Knotten, et al., 2015) Further, trust is crucial for the performance of a design team (Mila and Aki, 2012), lack of trust between the participants will have a negative impact on communication and the productivity (Erdem, et al., 2003). According to Larson and LaFasto (1989), trust consist of four elements: honesty, transparency, consistency and respect. Trust is broken if one or more of these elements is absent. Consequently, just adding a method or a tool is not adequate, there needs to be a basis for trust between the participants. According to Martin and Songer 2004, cited in: Ghassemi and Becerik-Gerber (2011) traditional contractual models (contract models like Design/Build, Design/Bid/Build (Lædre, 2009)) encourage each project member to concern itself with its own interest rather than the interest of the project as a whole. The design team therefore needs a contract model that engages the four elements of trust to gain an open and transparent process with high degree of collaboration. According to AIA (2007) mutual respect and trust is the single most important principle of Integrated Project Delivery (IPD). However, according to Smith and Rybkowski (2012), trust is currently rear on projects with traditional contracts and additional research is needed to determine if IPD and other relational contracts are capable of systemically supporting higher levels of trust. In sum: the design phase of a complex construction project is coordinated by mutual adjustment. For this to be efficient, you need direct communication and trust. This creates an environment for rapid design, but also possibilities of unethical behaviour.

RESULTS AND DISCUSSION

Not surprisingly – in light of the theoretical framework presented above – several ethical challenges are found to arise in the design phase. A main characteristic of this phase consists in its being potential in nature, making an unethical decision usually not detectable before far later in the building process. According to the impression of the interviewees, the ramification of such unethical decisions usually ends up costing both parties more than it would have if they had acted ethically in the first place. At least it feels like it cost more, in cases where such behaviour end up in court and the parties end up fighting for scraps.

All of the interviewees acknowledge the ethical challenges in the design phase. As described in the methodology chapter, however, getting them to talk about it was to some extent challenging. Nonetheless, certain highly interesting points came out of the interviews. Contracts and tender documents were identified as main points of contagion, and, consequently, creating the room for unethical decisions in the design phase. With insufficiently developed tender documents not describing the interfaces between the work packages, different disciplines can speculate on that and be awarded the contract on a price that seems cheapest. The final price can be totally different from the initial price. We can summarise the main findings as follows:

- **Pricing the tender documents**: If the tender documents are poorly described or even wrong (not buildable), they give the different disciplines opportunity to speculate and price their work package cheaply in coherence with the tender documents knowing that the client will have to order more. During the design process they know a lot of variation orders will appear, and that they can price changes high. Inversely, the client can omit necessary specifications, or include imprecision in the tender documents, in order to transfer risk to the contractor concerning the choice of solutions actually chosen. "*Pricing of the tender documents is only done of what is described, and not of what should be included to deliver a complete offer. That is the way the industry is. Procurement competence at the client is a problem"* n.n Consultant.
- **Exploiting cost reimbursement contracts**: Each discipline is responsible for logging its own hours in the project, and this logging is to some extent difficult to control for the client's project manager. Interviewees have experienced that the disciplines exploit that it is hard to predict how long it takes to come up with a solution and to design it. Although none admitted that they did it themselves, they were sure someone did log more hours than

actually spent on the project. ”*Usually, a consultant firm has several projects at the same time and if one of them is larger than the others it can be easy for the consultant in the firm to allocate resources from the smaller ones to the largest one.”* n.n Owners representative.

- **Shifting loyalty after transfer of contracts**: Designers can sign an initial contract with the client, which is transferred to a contractor later on. The designers shift from being contracted by the client to being contracted by a contractor. The client transfers their contract to the contractor. The interviewees perceive this as a problem for the designers, as the contractor will have considerable more focus on productivity than the client in the early phase. After the contractor has taken over the design contracts, the client still approach the designers directly with questions about design alternatives and technical solutions. However, even though the designers still feel obligated to answer the client since they had a former relationship, the contractor – which pays their bill – do not want to pay for this. The loyalty shifts from being with the client – who cares about the effectiveness – to being with the contractor – who cares about the productivity. The client tries to bypass the contractual frames of the contract to achieve something.
- **Sub optimising**: The decision process and the information needed to make a decision can be biased, so that the decision will gain the designer rather than increasing value for the total project. For instance, the structural engineer in a project can put severe constraints on the architect’s room to manoeuvre when recommending the client to choose between cast in situ and precast concrete. Another example is when the designer knows about a better design solution, but deliberately ignores it because it involves extra work and the benefit comes to the other participants. According to the interviewees, this problem becomes larger the more specialist designers that are contracted in the project.” “*I have experienced that consultants has withheld informations so they can use an easier solution. They do not want to explore the possibilities*.” N.n Architect.

To these main points, several interesting stories concerning ethical challenges experienced in the design phase emerged. For instance, there was one case where the contractor in a design build contract discovered a questionable solution to fire safety. The contractor hired in a third party fire consultant and got him to look over it and come up with a safer solution. The contractor sent a variation order request to the client, who rejected it because of a higher price and a reference to the first fire consultant that had written a note about his solution being in line with fire safety regulations. The contractor was therefore posed with the following ethical question; should he just follow the contract, or should he upgrade the fire safety. This was a large shopping mall, so a fire can have large consequence. The contractor did not want to take this risk (even if he – according to their contract – can argue that he is not responsible) so he upgraded the system. Now, after the commissioning of the building, the client still does not want to pay the upgrade bill. The case ended up in court.

According to our comprehension of the problem field, a close reading of contracts and tender documents form a main structural reason that open room to act in what is perceived to be unethical practices. The lack of trust among team members –

especially concerning their loyalty to the project – does equally seem to play an important role. The theoretical framework has illustrated that the reciprocal and iterative design process is challenging to manage properly with traditional management tools. There is a need for a more collaborative management style with a high degree of trust between the participants. In complex projects the ethical challenges are easier to misuse the more participants there are in the design team. Consequently, the participants can hide behind a "false" trust, and this opens for ethical challenges.

Of a more general nature, the access to information in construction projects is typically askew. Such projects involve a high number of actors, creating interfaces between roles where influence over the decision making process is characterized by lack of transparency on the subject of loyalties. Specialists are in general found to drive costs upwards, as their superior knowledge in parts of the project lead to increased costs in these particular areas.

CONCLUSION

From this preliminary study we have observed that what is characterised as unethical behavior arise among all the three main parties in the design phase i.e. client, contractor and designers (architects and consulting engineers). We have not in the analysis found sufficient evidence to conclude that certain forms of unethical behavior are particular to projects using lean principles. Rather, the principles seem generalizable to the design phase in the industry as a whole.

The main challenges encountered in the material consist in poorly described tender documents, biased logging of work hours, shifting and unclear loyalties among design team members, and sub-optimizing of work processes for own gain. Not surprisingly, the interviewees were reluctant to share such information with the initial analysts involved in the study leading up to this paper. Interestingly, the interviewees came up with several anecdotes revealing the true potential for unethical practices in the design phase, when enquired further.

A close reading of contracts and tender documents were revealed as a main structural reason that open room to act in what is perceived to be unethical practices. The lack of trust among team members – especially concerning their loyalty to the project – was equally identified as playing an important role.

As long as what is perceived unethical is not described, the field of design will be exposed to unethical behaviour. This paper constitutes one step to filling this knowledge gap. The limited number of interviews poses an obstacle to the generalisation of the results. More research therefore is needed to comply with this need. However, the findings seem to correspond to the limited research carried out internationally.

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PEOPLE, CULTURE AND CHANGE

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MISCONCEPTIONS OF LEAN: WHY IMPLEMENTATION FAILS

Chesworth, Brianna[1]

ABSTRACT

Successful implementation of lean strategies is more than an overall acceptance of ideology, tools and practices; it is about acceptance of the changing culture. Culture drives implementation through the adoption of best practice principles providing the organisations with a sense of achievability. To date research in the field has provided companies with a false sense of implementation security; promoting many social, financial and cultural benefits without the acknowledgement of the overall challenge – knowledge. Utilising the action research method this paper explores the concept of knowledge and is application in lean implementation within a leading Australian construction company. The paper highlights a need for the streamlining of lean knowledge at the core of implementation strategizing. The paper proposes that developing an awareness of knowledge in a theoretical context will assist in challenging cultural behaviours within the practical application.

KEYWORDS

Implementation, lean construction, misconception, organisational culture.

INTRODUCTION

Existing interpretations of lean promote social (process inputs), financial (savings outputs) and cultural (attitude outputs) benefits of lean implementation without the full acknowledgement of the overall journey. Key to this journey is the transfer of knowledge between what is known, what is conceived, what is not known and what can we learn.

Knowledge whether through the development of education (Hirota & Formoso, 1998; Alves, Milberg and Walsh, 2010), leadership (Orr, 2005) or open collaboration with others (Howell, 1999; Buch & Sander, 2005; Erikson, 2010) allows individuals to develop confidence in their ability to bond and advocate lean (Chesworth, London and Gajedendran, 2011). The advocating of lean through open collaboration, communication and integrity of working groups allows the streamlining of ideas, process and maturing of cultures (Chesworth, London and Gajedendran, 2011).

Theoretically, knowledge is simply the development of skills and retention of facts and information through education and experience. Practically, knowledge is more about relationships, learning from others, and the application of learning and comprehension of failure. To understand why implementation fails implementation contexts need to be defined.

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LEAN IMPLEMENTATION CONTEXTS

SOCIAL

Social contexts (process inputs) are best understood by understanding why organisations first make the decision to implement lean (Chesworth, London and Gajedendran, 2011). Research within the lean community has moved beyond the defining of processes to explore more detailed social agendas such as the relationship between implementation and skill (Simonsen and Koch, 2004), emerging social construction networks (Silvon, Howell, Koskela and Rooke, 2010; Priven and Sacks, 2013) and lean behaviours (Fauchier and Alves, 2013). Nonetheless a sugar coating of implementation suggesting a holistic acceptance of ideology with immediate benefits and neglecting the true journey still underpins a large proportion of research (Chesworth, 2013).

- Implementation outputs from a social perspective can include:
- Standardisation of the organisation's workflow (Howell and Ballard, 1998, 1999; Morrey, Pasquire and Dainty, 2010);
- Elimination of non-value add activities and/or processes (Howell, 1999); and
- Improving supply chain performance and collaboration (Erikson, 2010).

Although there has been some discussion on social relationships within the context of lean implementation; how we as individuals and in teams utilise knowledge is not clear. How we interact, teach, learn and transfer knowledge will assist in further understanding perceptions of lean implementation failure and assist in providing a holistic understanding of implementation best practice.

FINANCIAL

Financial contexts (saving outputs) are representative of the implementation productivity gains such as workflow stabilisation (Ballard and Howell, 1994; 1997), waste minimisation or elimination (Alarcón, 1994) and process streamlining (Cox, Ireland and Townsend, 2006). Typical characteristics of existing financial implementation contexts include but are not limited to:

- Percentage improvements or achievements in workflow (Marosszeky and Karim, 1997) ;
- Specific financial gain over the life cycle of the project or overall cost savings for the organisation (Cox, Ireland and Townsend, 2006); and
- Promotion of the value chain concept (Akinci, Fischer and Zabelle, 1998; Lindfors, 2000)

Issues relating to long term commitment, time and financial burden are limited in their representation in current interpretations. Key to understanding the failure of implementation is linked to the relationship between implementation inputs and outputs developed through strategic planning. Understanding this relationship will further assist in determining implementation best practice.

CULTURAL

Cultural contexts (attitude outputs) are often presented with an overarching implementation acceptance or rejection (Chesworth, 2012). Idealistic cultural representations further sugar coat implementation by suggesting implementation immediately leads to:

- Open collaboration and cooperation (Coffey, 2001; Arbulu and Zabelle, 2006);
- Open lines of information sharing (Orr, 2005; Buch and Sander, 2005);
- Empowerment amongst the workforce (Buch and Sander, 2005; Ballard, 2014)
- Total commitment across the whole organisation (Dainty, Moore and Murray, 2007).

Green (1998; 1999), Green and May (2005) and Winch (2003) suggest the emergence of organisational distrust directly linked to lean implementation. Despite conflicting interpretations the relationship between implementation and knowledge is not defined. This is particularly prevalent in understanding how we learn, why we learn and what we do and do not know and the impact these concepts have on an organisation's ability to successfully implement lean.

THE PROBLEM

The problem that is prevalent within current lean implementation literature is that there is not one true way to successfully implement lean. Rather lean implementation is representative of social, financial and cultural contexts that seek to provide implementation bias representative of misconceptions without acknowledgement of the true lean journey. The aim of the paper is to understand the application of lean, the misconceptions that emerge during implementation and overcoming implementation set-backs. The research question is therefore:

"What are the misconceptions of organisational lean implementation?"

METHODOLODY

The research aims to identify and understand why lean implementation fails and how a lack of innovation knowledge leads to the presence of underlying misconceptions. A qualitative methodology is used, with the investigative narrative guided by constructivist principles (Bryman, 2008; Denzin and Lincoln, 2011). A constructivist approach provides a framework to explore and understand present misconceptions aligned to implementation failure rather than quantifying implementation failure.

Action research is an applied research approach "*that treats knowledge as a form of power and abolishes the line between research and social action*" (Neuman, 2006: p.28). Action research provides an opportunity to explore the implementation journey of an organisation through active participation; by advancing knowledge and increasing the awareness of lean. In participatory action research the researcher typically assumes an active role in the formulation, design and carrying out of the research (Stoecker, 1999). However due to the structure of Organisation ABC a consultative action research approach (Neuman, 2006) is undertaken. In consultative action research the researcher takes a consultative/collaborative role, assisting with but not having complete control over the research process (Neuman, 2006).

As the research involves differing perceptions and site needs the theoretical framework will be guided by the principles of thematic analysis. Thematic analysis provides a framework to identify and understand similar trends, themes and awareness of the core misconceptions emerging within the investigation (Boyatzis, 1998).

The results are presented in a case study format. Utilising the case study format provides the opportunity to analyse holistically the literal and theoretical replication between "that is or may be" present across the organisational sites (Flyvbjerg, 2006; Yin, 2013).

ACTION RESEARCH STRATEGY

Location of the selected sites impacted the intended consultative approach; further impacting strategy was the proposed timeframe. Organisational senior management provided a 2 year window to address feasibility as well as early rollout of principles across the selected sites. Table 1 Organisation ABC Action Research Strategy provides an overview of the data collection strategy.

Table 1: Organisation ABC Action Research Strategy

Element	Approach
Observation	6 month period; spending approximately 5 weeks per site; Identification of site change agents
Strategic direction development	1 month period; tailored made to each site; alterations made by senior management to reflect organisational requirements
Training programme development	6 month period; developed with consideration towards the educational needs of the workforce; training in tooling included time and motion studies, visual management training and specialised lean six sigma project training.
Transition to site run implementation	Hand-over of site implementation to identified champions
Ongoing Visitation	12 month period; ongoing site visitation, further coaching and mentoring of the organisation and progress monitoring

RESULTS

Data was collected over a 2 year period. The results and analysis has been condensed to highlight changing attitudes, knowledge development and the emergence of lean misconceptions over the implementation time period aligned to the action research strategy. The organisation will be presented first.

THE ORGANISATION

Organisation ABC is a large multi-national construction contractor employing over 5,000 people across four (4) regions including Australia, Africa, the USA and Europe. In the last 3 years the organisation has been severely impacted by significant economic downturn across the infrastructure, manufacturing and mining sectors with workforce cuts over this period of 40%. Other significant factors impacting the organisation and further influencing the decision to implement lean included:

- Increasing business overheads;
- Operating system failures due to inefficiency and delayed roll out of updates;
- Increased client focused QA/QC of goods and services;

- High employee turnover;
- Increased safety incidents across key sites; and
- Decreasing win:loss ratio in successful tender bids.

Within 12 months of the economic downturn senior management made the decision to investigate the feasibility of lean principle application within selected Australian sectors of the business. Implementation was focused on five (5) sites as described in Table 2.

Table 2: Organisation ABC Sites

Site	Employees	Services
QLD 1	450	Regional location; Provides functional support for site operations; functional support include HR, legal, procurement, marking and WHSEQ
QLD 2	50	Brisbane CBD location; involved in EPC projects (Engineering, Procurement and Construction) to the value of $600million
NSW 1	125	Regional location to save on costs; overhaul and repair of construction equipment; workshop, engineering and service sub-divisions
NSW 2	32	Regional location to save on costs; on-site construction equipment servicing
NT	57	Manufacturing division; specialised construction equipment

ORGANISATION BIAS

Within Organisation ABC there is a presence of implementation bias particularly among the satellite sites regarding the adoption of lean principles. Known bias emerged during initial site consultation and is present due to at the time recent employment of individuals with lean qualifications and/or knowledge. The presence of bias has impacted the study due to multiple individuals implementing strategies without full awareness and understanding of the contextual impact of their actions; particularly the transfer of knowledge.

OBSERVATION

Complexity in structure and locality of Organisation ABC sites impacts overall knowledge not only in existing organisational systems but also the acceptance of change. The structure of Organisation ABC is representative of operational capabilities managed by individual general managers reporting to a CEO. Communication lines rarely extending beyond the operations silo (except at a senior leadership level).

Time zones have a significant impact on the operability of the organisation. Within the Australian branch sites operate across four (4) time zones the majority of the year (on average time-zone differences are between 1-2 hours); which further impacts management.

Overarching site governance is an integrated management system (IMS). The IMS dictates business policies, processes and procedures. Despite the presence of the IMS satellite sites including temporary project teams (TPT) experience high levels of communication breakdown, in part due to a lack of system awareness and input in key business decisions.

Morale is generally higher at satellite sites than at QLD 1 (head office) site as these sites are run as independent businesses focused on delivering specialised services to elite clients. These sites are also managed charismatic leaders who are more open to serving the needs of clients rather than running completely to a corporate agenda.

STRATEGIC DEVELOPMENT

The complex management style of Organisation ABC was present in the strategic development phase of the study, particularly in the influence of QLD 1 in ensuring all sites set and achieve similar goals. QLD 1 tended to ignore the individual requirements and needs for satellite sites in favour for the development of a high level approach aimed at ensuring acceptance at a senior level rather than a site level.

All satellite sites were keen to become actively involved in the implementation process; however the attitudes of senior leaders shifted immediately preceding the discussion of the strategic plan and aligned site goals. Satellite sits felt the development of the strategic plan at a corporate level set unachievable and unrealistic expectations; many senior site managers suggesting the setting of a corporate agenda with implementation at a site level deliberately sets that site up for failure.

TARGETED TRAINING PROGRAMMES

Although satellite sites were excited about beginning the lean journey time and cost allocation for appropriate training programmes was limited due to the high levels of work and location of TPTs. This trend was consistent across all sites.

Due to levels of work, satellite sites were provided specialised on the job training through the use of specific tooling. Sites NSW 1, QLD 2, NSW 2 & NT had prior to the study been in some form implementing lean principles to varying degrees via 5S. Implementation at these sites was being driven by individuals who had been exposed to lean previously however implementation had occurred with without the development of a specific or specialised strategic direction. NSW 1, NT & NSW 2 were in addition implementing lean to an extent via guidance from recent external audits conducted at the sites; a stance that QLD 1 endorses as an additional avenue for activity improvement.

Site champions were easily identifiable at NSW 1, NSW 2 & NT; however specialised training with these champions was difficult due to existing attitudes towards organisational requirements of the organisation and conflict with their existing knowledge. Discussions with champions were ongoing regarding tool use and application at each site; despite initially resistance, champions saw the benefit early on. Early acceptance allowed an ease of improvement project identification and management.

TRANSITION TO SITE MANAGEMENT & CONTROL

All sites were positive that they could maintain control of implementation at a site level as driven by the selected site champions.

ONGOING VISITATION

QLD 2 and NSW 2 were the only sites that maintained ongoing commitment to the QLD 1 development strategic direction for the implementation of lean. QLD 2 maintained a high level of commitment and thrived due to an overall need to improve their existing systems.

Implementation in NSW 1 & NT was affected by a high employee turn-over particularly those employees identified as site champions. Furthermore, NSW 1 was influenced by an ongoing trend of everyone thinking they were already continuous improvement team with experts, trained in the use and application of lean principles. In NSW 1 there was no commitment to the developed direction with many within this division of the organisation implementing lean to benefit individual departments.

Sites cited process standardisation, corporate agenda strategizing as well as a lack of organisational system knowledge to be underpinning implementation failing within the organisation. Although present the impact on Organisation ABC was identifiable more so from a lack of awareness of the overall implementation purpose than a lack of system knowledge.

A DISCUSSION ON MISCONCEPTIONS

Three (3) misconceptions of lean emerged within the organisation. The three misconceptions are reflective of a lack of knowledge not only of lean but also of the organisation's longer-term commitment during implementation. The discussion is focused on these three misconceptions to provide an examination of organisational trends.

MISCONCEPTION 1: STANDARDISATION IS ESSENTIAL FOR SUCCESS

Standardisation is a core ideal of the lean movement (Womack and Jones, 2003; Liker, 2003). Within the organisation implementation standardisation was thought to be required to align the overall operating systems as well as a requirement to maintain quality, safety, environmental and manufacturing certification. Process standardisation emerged due to certification compliance and maintenance activities which underpin the organisation's ability to operate within specialised industries. Process standardisation is approached as a way of controlling the communication of information across the organisation and emerges as a result of the organisation experiencing financial and time constraints that ultimately impacts the implementation commitment.

Guiding process standardisation are organisational champions (supported by the WHSEQ function) who push as part of standardisation a corporate agenda focused towards compliance. This agenda is representative of the organisation attempting to streamline product delivery across all sites which require the same systems and processes. This is misguided particularly in this organisation as each site is so characteristically different that many of the current systems do not already readily comply with the needs of satellite sites. This lack of awareness and knowledge of organisational operations influences misconception 3.

Sites that have succeeded with lean implementation utilise to a degree the standard operating systems; however have adapted some processes to be driven by client needs and requirements.

MISCONCEPTION 2: CORPORATE AGENDA DRIVEN IMPLEMENTATION

Lean implementation is driven by a need to change and is directed in most organisations from senior leadership (Chesworth, 2013). Within the organisation implementation is championed by key WHSEQ representatives (based in QLD 1) with minimal buy-in from senior leadership. Implementation management by WHSEQ representatives' forces the presence of misaligned agendas driven by corporate functional needs, such as overarching compliance and certification. The positioning of implementation representatives within a corporate environment contaminates the journey as acceptance at satellite sites is less likely to occur as individual site needs are neglected.

The organisation already struggles with negative personnel attitudes towards head office, an attitude heightened when lean was first introduced into the organisation. The majority of satellite sites saw the initial decision as a way of further controlling site specific processes, policies and procedures; this is particularly prevalent in current document control standardisation.

Frame-working implementation to the individual needs of satellite sites enables reflection on the overarching corporate direction while providing an opportunity to establish site specific goals and objectives. The overarching corporate agenda was almost entirely eradicated within the organisation when satellite sites took control of implementation during site transitioning.

MISCONCEPTION 3: SUCCESS WITHOUT A STRATEGIC DIRECTION

The organisation has experienced high levels of rejection during early phased implementation due to believing success can be achieved without a strategic direction. This attitude transcended satellite sites as implementation was driven by individuals without formal training, but had been exposed to principles in previous employment. At these sites implementation occurred without set objectives and recognition of the true commitment required to maintain commitment.

The structure of the organisation and locality of sites negatively impacted employees' confidence in their own skills and knowledge of lean and continuous improvement. Strategic planning and developmental awareness applied through lean tool education and mentorship provided satellite with basic skills to commit to a tentative direction early on in the implementation journey.

From an implementation perspective early education whether tool application or training provides individuals and teams with the confidence and ability to challenge implementation champions throughout the journey. Though, through active participation employees were able to overcome many of their fears; particularly those linked to the inability to put themselves out of their existing comfort zones.

CONCLUSION

Awareness of implementation misconceptions provides organisations with the ability to prepare for potential lean failure, particularly at satellite sites. Lean failure should not be the ultimate goal of implementation rather it the understanding of how and why individuals, teams and sites react to and utilise knowledge to overcome implementation set-backs.

Identifying implementation misconceptions early assists in organisations to develop the relevant knowledge and skills, particularly for those who are not lean trained but are still required to participate in implementation. The sharing of knowledge provides organisations with the skills and tools to challenge organisational status quo; in turn creating a culture that is empowered to continually improve.

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BARRIERS AND SUCCESS FACTORS IN LEAN CONSTRUCTION IMPLEMENTATION - SURVEY IN PILOT CONTEXT

Sandra Cano [1], Jonathan Delgado [2], Luis Botero [3] and Oscar Rubiano [4]

ABSTRACT

The study identifies a set of barriers and critical success factors (CSF) involved in the implementation of Lean Construction (LC) through three phases: Literature's Collection, with analysis and obtained information processing; Characterization and classification of barriers and CSF associated with the implementation of LC; and Identification of barriers and CSF in construction companies in the Colombian context, based on their experiences in the implementation of LC. 83 academic articles published between 1998 and 2014 were examined, being identified 110 barriers and 51 CSF based on experiences of LC's application around the world. They were grouped into six "Master Factors": people, organizational structure, supply chain, external value chain, internal value chain and externalities. The obtained information from the data was analyzed using a cause-effect matrix and a structural analysis with MIC MAC method, and the most critical barriers and success factors were determined. Furthermore, the exploration in the pilot context demonstrated a common criticality in most of these factors, and it was shown that its appearance is related to the level of evolution of LC's application.

KEYWORDS

Barriers, Critical Success Factors, Lean Construction, Action learning, Commitment.

INTRODUCTION

To integrate LC philosophy in a construction organization, it is recommended to understand and anticipate situations (barriers) that might be opposed to a proper implementation, as well as taking hold of those (CSF) that can help ensure its success based on similar experiences in other contexts. A barrier prevents a step or an action,

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while a success factor is something that must occur — or that must not happen — to achieve the objectives, this factor becomes critical if its compliance is absolutely necessary for achieving those objectives. These situations are presented internally and externally in the organization and the project, and understanding them is of maximum importance to propose actions to contribute to forewarn their occurrence or to mitigate their impact in terms of barriers, and in another sense, to provide a guide towards strengthening those conditions that contribute to the successful implementation of LC using the CSF.

BARRIERS AND SUCCESS FACTORS IN LC

RESEARCH RETHOD

Primarily the search was conducted in the database of the International Group for Lean Construction - IGLC (www.iglc.net) with references from 1996 until the present year. This database presents a complete collection of publications in LC, thus this was the main reason to select it as the most important source for this research.

The bibliographic references were complemented with databases such as ScienceDirect, Emerald, and SpringerLink. Because the literature and research on the topic LC is huge, especially on the above databases, the search was delimited using keywords (filters) as: "barriers in the implementation", "obstacles", "difficulties", "hurdles", "hindrances", and "critical success factors". The search was directed to Google Scholar to finish this first stage of information gathering. The obtained articles were classified according to the publication year.

In the next phase of research, it was paid much attention to the quotations of authors and references of each article on the subject of barriers and success factors. The cited articles were looked again at the already suggested databases. This procedure was performed repeatedly and with each of the found articles, applying inclusion and exclusion criteria to complete the list for the study.

It was necessary to undertake an exclusion process of articles, which were not so relevant for this project. Exclusion criteria were: general publications and articles focusing on the implementation of Lean Manufacturing. Only documents in English and some in Spanish language were taken into account. The most important inclusion criterion was to select articles that clearly express the different obstacles or CSF that impact the implementation of LC, which have been documented in cases from different parts of world in construction projects.

DATA PROCESSING

Classification of the selected articles was done, summarizing the most important and relevant aspects to the research, especially the list of barriers and/or success factors identified by different authors. Furthermore it was took into account the author or authors, the country in which it was developed, the publication year, the identification method of factors, the used classification or categorization system, characterization of concepts, and the analysis and final discussions of each author.

When the total quantity of articles was revised, it was completed a list of critical factors of each of the collected publications. Afterwards it was consolidated a list that would group all barriers and success factors. For each factor was written the source from which was obtained, the author who described it, and the quantity of different places where it has been also identified.

SEARCH RESULTS

During the literature review, it was identified 110 barriers and 51 CSF. The situations encountered were documented from 83 academic articles published between 1998 and 2014 (in this article only 26 references are presented), based on experiences in applying LC in the construction industry within countries such as China (Pheng and Shang, 2011; Shang, et al., 2014), United Kingdom (Bashir, et al., 2010; Sarhan and Fox, 2012; Sarhan and Fox, 2013), Vietnam (Khanh and Kim, 2013), Malaysia (Abdullah, et al., 2009; Jeni, Luthfi and Akasah, 2013; Marhani, et al., 2013), Mexico (Cervero-Romero, et al., 2013), Nigeria (Olatunji, 2008; Ahiakwo, et al., 2012), Dominican Republic (Senior and Rodriguez, 2012), Ghana (Ayarkwa, et al., 2005; Ayarkwa, Agyekum and Adinyira, 2011), Brazil (Viana, et al., 2010), Middle East (Alsehaimi, Tzortzopoulos and Koskela, 2009), Uganda (Alinaitwe, 2009), Germany (Johansen and Walter, 2007), USA (Haupt and Whiteman, 2004; Kim and Park, 2006; Hamzeh, 2011; Pekuri, et al., 2012), Singapore (Dulaimi and Tanamos, 2001), Chile (Alarcon and Diethelm, 2001; Alarcon and Seguel, 2002; Alarcon, et al., 2005), Finland (Pekuri, et al., 2012), and Lebanon (Gherbal et al., 2012).

CHARACTERIZATION AND CLASSIFICATION OF FACTORS

According to the definition and characteristics of each identified factor, the barriers are grouped into the Master Factors and categories, and improvement measures relating them to the identified CSF are presented.

MASTER FACTORS

People: Related to people who are involved or participate in construction projects. This group was separated into four categories: 1. Education and training, 2. Top Management, 3. Operation, and 4. Attitude and culture.

Organizational structure: aspects related to the structure of the organization, means or procedures necessary to achieve organizational goals, the flow or resource management, interrelated systems within the organization, among others. The categories of this group are: 1. Philosophy, 2. Resources, and 3. Structure.

Supply Chain: Supply chain involves all parties directly or indirectly to satisfy a customer. The aim of the supply chain is to maximize the global generated value. This consists of four categories: 1. Management, 2. Resources, 3. Technical aspects, and 4. Processes and systems.

Internal value chain: All processes, procedures and stages that include planning and control of project's development, in this case, of construction. There are three categories in this section: 1. Management, 2. Planning, and 3. Control.

External management and value chain: The value chain describes the full range of activities that are required to bring a product or service from conception, through the different stages of production, delivery to final consumers, and until final disposal after use.

Externalities: Those aspects that impact the project's development and as well as the LC's implementation as external factors. Three categories are distinguished: 1. Government, 2. Construction's nature, and 3. Other.

OVERCOMING WAYS

Ways to overcome barriers are influenced by local conditions of the industry, development and evolution of LC within construction companies (maturity), criticality and relevance of each of the identified situations, among others. A set of CSF is used as elements which are opposed to the identified barriers as an efficient manner to overcome or minimize their impact on the LC's implementation in construction projects.

People: Includes appropriate training and education, comprehensive understanding of the Lean philosophy, closer relationship between academia and industry, support and commitment from the top management, effective leadership, clear definition of roles, responsibilities, functions and levels of authority, selection and development of the right people, collaboration, inclusion of specializing in LC professionals, promises with commitment, motivated people to change, honesty and trust between project participants (transparency), discipline, respect for authority and deep aversion to waste.

Organizational structure: Comprises setting process goal in the short and long term, full implementation of the selected LC tools, incorporation of pilots testing, more focus and attention to customer needs, a holistic perspective, and solution of root problems. Management must provide adequate resources to support cultural transformation, have a mentality of order and active participation of all stakeholders in the organization. A balance of the interests of all participants, constitution of an improvement committee responsible for the implementation, incorporation of lessons learned, sharing information appropriately, improvement of coordination and cooperation, and reduction of hierarchical levels.

Supply Chain: Includes ensure an effective and open communication, establish closer and collaborative relations with suppliers, customers and consultants; to support the thinking transformation, working methods, promoting integration, coordination, and cooperation. Standardize and ensure complete and accurate designs. Establish an incentive system, awareness that the right process will produce the correct result.

Internal value chain: It aims to establish a better management of the production chain, employing an effective and open communication, better coordination and cooperation, a clear methodology and management processes. Establish a solid plan of action of extensive planning with enough anticipation.

External value chain: Comprises improvement of comprehension and understanding of the same administration and value chain, it is necessary to develop a system of training and education for those involved in its management.

Externalities: Includes an establishment of an adequate system of risk management that encourages more participation of all stakeholders, and an appropriate contractual agreement that balances the interests of all participants.

EXPLORATORY PILOT CONTEXT

A sample of 26 Colombian companies was studied. The LC's heads of the organizations were interviewed through personal meetings. The respondents work in organizations carrying out construction projects in the major Colombian cities, and have experience in implementing LC between 1 and 10 years. The built and applied instrument for data collection was an interview based on an exploratory survey conducive to know the process of implementing Lean in the organization. The objective was to identify problems or barriers encountered in this process, to determine the critical factors for successful implementation of LC, and to collect the final recommendations about the implementation process by interviewed. This instrument was validated through the evaluation by a panel of experts, who contributed to determine the final survey items which would lead to concise results. With the interviews it was able to identify a list of barriers and success factors in the Colombian context, and thus the common elements were related and analyzed with the list which was collected in the literature review.

From this exploratory test, it was identified that 56% of the barriers and 68% of the CSF of the list of obtained factors from literature, are presented in Colombian construction companies. In the local context were identified other barriers and CSF that have not been reported in the literature, some of them associated with the current conditions of the construction sector in Colombia. These are:

Barriers: 1. Difficulty in having appropriate people for LC's application. 2. Lack of identification and control of waste. 3. The results are not fast, and often only partially visible. 4. Poverty and social problems. 5. The own informality of local industry. 6. Lack of self-esteem and initiative on the part of individuals.

Success factors: 1. Making decisions in teams, collectivity. 2. Provision of capable and trained contractors in LC fundamental aspects in consistent with their field of work. 3. Reduction of labor turnover at all hierarchical levels - Continuity of workforce in projects. 4. Improvement of life's quality of workers. 5. Establishment of a continuous process of measuring losses. 6. Socialization, for the sector companies, of the individual results of the LC's application. 7. Destination of time to think and plan. 8. Generation of confidence in the philosophy and the principles. 9. Persistence in cleaning and order. 10. Work in the formality of the construction guild.

CRITICALITY ANALYSIS

Based on the gathered information, it was performed a descriptive exploratory analysis of the data, extracting the most significant and influential barriers and CSF in the projects and organizations. To identify relationships between the analyzed variables, some tools such as a cause-effect matrix and the MIC MAC structural analysis method were used, which are presented in the following subsection. The statistical treatment, to which were submitted the answers given by the respondents in the sample of visited companies in this investigation, led to obtain clear results that show not only the state in the maturity of the application of LC in companies of the Colombian context, but also the criticality of the identified factors, from a rigorous study of causalities and influences between them.

CAUSE-EFFECT MATRIX

The level of criticality or relevance of the obtained factors was determined from a cause-effect matrix, establishing causal relationships between the CSF and the barriers. In the top row of the matrix are aligned the outputs (the 110 barriers). In the left column are registered the inputs (the 51 CSF) (Hernandez and Reyes, 2007). To each output is given a priority factor, which is calculated with the frequency of each element in both contexts (identified in the literature and in the Colombian companies), the most frequent element is assigned with the highest priority factor (9 for the most frequent and 1 for the less frequent).

The matrix was completed by evaluating the relationship of each input with each output: if the input variable has no effect on the output variable was evaluated with zero (0), if the input variable has a small effect on the output variable was assigned with one (1), and thus, if the effect increases it might reach an assessment of ten (10) if the input variable drastically affected the output variable.

With the completed matrix the criticality is calculated by multiplying the relation values for priority factors. It estimated the total sum for each input and each output. Finally the cause-effect matrix is completed with all calculations, highlighting the most critical inputs and outputs based on the relationship among them and the priority factors. According to the score, the 10 most critical barriers and the 10 most critical success factors are listed below:

Critical barriers: 1. Cultural problems; 2. Lack of participation and integration of all stakeholders; 3. Lack of knowledge, understanding and awareness of Lean; 4. Resistance to change by managers; 5. Dichotomy design - construction; 6. Resistance to change by workers; 7. LC insufficient training; 8. poor and inadequate planning; 9. Lack of proper attitude; 10. Lack of commitment of continuous work.

Critical success factors: 1. Participation of all stakeholders; 2. Better coordination and cooperation; 3. Overcoming resistance to cultural change; 4. Change in the mindset of employees; 5. Motivated people to change; 6. Teamwork; 7. Development and selection of the right people; 8. Honesty and trust among participants - transparency; 9. Effective Leadership; 10. Training and appropriate education.

STRUCTURAL ANALYSIS

MIC MAC is a technical tool to describe a system using a matrix that connects components (Guzman, et al., 2005). It allows examining and identifying influential and dependent variables of the study. The MIC MAC structural analysis method is used to raise questions and make a collective reflection of the study group, reducing the complexity of the system to specific points, helping to identify the most influential and the most dependent variables.

Crossed-impact matrix and motricity – dependency analysis

For structural analysis are considered the factors with a high level of importance, relevance, or criticality which were identified in the cause-effect matrix; to establish what and how the influence and dependence of each critical variable is. For the analysis of motricity - dependency it is necessary to build a crossed impact matrix with double entry, one for the 10 critical barriers and other for the 10 CSF. In this matrix was analyzed the dependence of each variable, with respect to the others, from left to right and the motricity from top to bottom. This relationship is evaluated with three when the degree or level of dependence or influence is high, with two if that level is moderate, with one if it is low, and zero if there is no dependence or influence. Finally the values in each row are added to determine the dependence of each factor (d) and the values of each column are added to determine their level of influence (m). With those totals, the percentage of dependence and influence can be obtained for each variable, which are shown below.

Barriers: lack of participation, integration and interest of all stakeholders is the most dependent barrier (19.8%), followed by poor planning (16.5%). On the other hand the less dependent barrier is insufficient training (1.1%), followed by lack of understanding and knowledge Lean (5.5%) and dichotomy design - construction (5.5%). Lack of proper human attitude and cultural problems are the most influential barriers (16.5%), followed by resistance to change by managers (14.3%). On the other hand the less influential critical barrier is poor and inadequate planning (3.3%), followed by the dichotomy design - construction (5.5%).

CSF: participation of all stakeholders and motivated people to change are the most dependent success factors (14.7%), followed by teamwork, better coordination and cooperation, and resistance to change by managers (13.8%). On the other hand the less dependent CSF is appropriate training (1.7%), followed by the development and selection of the right people (3.4%). In regard to motricity or influence effective leadership is the most influential CSF (15.5%), followed by development and selection the right people and change in the mindset of employees (12.9%). On the other hand the less influential critical factor of success is better coordination and cooperation (3.4%), followed by motivated people to change (6%).

Then appear four types of variables and are sorted to identify the essential ones or keys in the system: **Zone 1.** When the variables have low motricity and are little dependent: variables are little influenced by the others that constitute the system, they exert little influence on the other variables. **Zone 2.** When the variables have low motricity and are very dependent: variables are strongly influenced by the others that make up the system; they offer little influence on other variables. They are called outcome variables. **Zone 3.**When the variables have high motricity and are little dependent: variables exert strong influence on the others that make up the system, but they can be slightly affected. They are called independent or conditions variables; or variables of the power area. **Zone 4.** When the variables have high motricity and are very dependent: variables exert strong influence on the others that constitute the system; they are very influenced by other variables. They are called random variables or variables of the conflict zone. They are influenced by the conditioning variables and influence on outcome variables.

It is necessary to graph each of the analyzed critical factors in a motricity vs. dependence chart, with the previously obtained data in the crossed impact matrix, to determine in which zone they are located. In the Figure 1 are positioned each of the 10 critical barriers according to their respective values of influence and dependence. Similarly the 10 CSF are located in the Figure 2.

Barriers located in zones 3 and 4 are very critical (Zone 3: 1. Cultural problems; 3. Lack of knowledge, understanding and awareness of Lean; 4. Resistance to change by managers; and 6. Resistance to change by workers. Zone 4: 9. Lack of proper attitude), because they have high influence on the other barriers, and that fact could have a major negative impact on the Lean implementation; especially the more independent variables (Zone 3, higher criticality). Barriers in zones 1 and 2 are not so critical over the others, because they present little influence.

The success factors most critical, namely, most important to increase the possibility of success in the Lean philosophy implementation, are the numbers 1, 3, 4, 7, 8, 9, and 10 (Zone 3: 7. Development and selection of the right people; 8. Honesty and trust among participants - transparency; 9. Effective leadership; 10. Training and appropriate education. Zone 4: 1. Participation of all stakeholders; 3. Overcoming resistance to cultural change; 4. Change in the mindset of employees), because they are located in zones 3 and 4 (although the ones in the area 3 could be the most critical).

This final map of criticality of the barriers and CSF, defines more clearly the target factors that guide the efforts and prioritize actions for efficient progress in the implementation of LC in construction systems in the Colombian context.

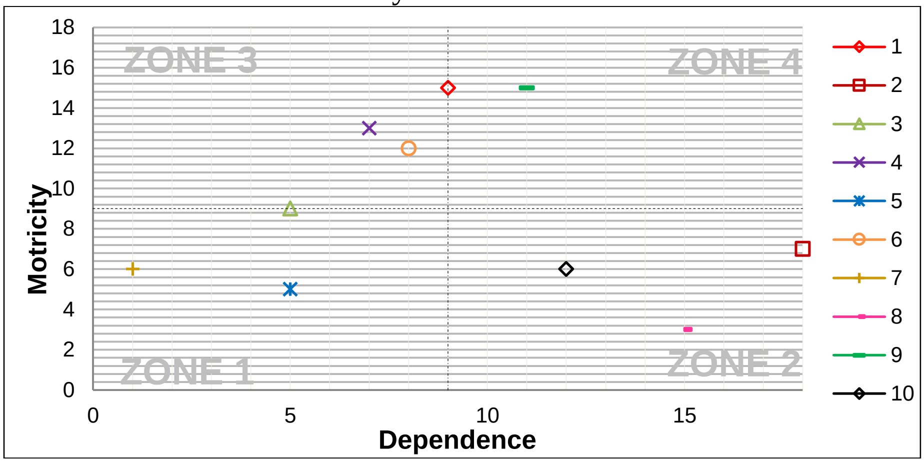

Figure 1: Graph of Motricity vs. Dependence of the 10 critical barriers. Enumerations correspond to the barriers identified in the cause-effect matrix (Source: own authorship).

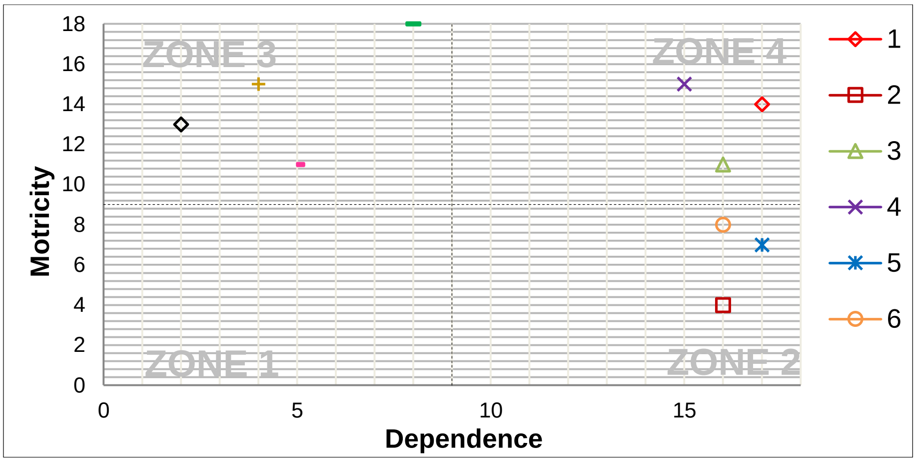

Figure 2: *Graph of Motricity vs. Dependence of the 10 CSF. Enumerations correspond to the CSF identified in the cause-effect matrix (Source: own authorship).*

CONCLUSIONS

Prior to the LC's implementation, knowing this wide set of barriers, it is advisable to provide a way to prevent their occurrence or mitigate their impact, based on knowledge of the CSF to strengthen the LC's application. After the criticality analysis of the factors in the cause-effect matrix and the results in the MIC MAC analysis, it was identified that the most important and influential barrier is related to cultural problems and the most influential CSF is the development and selection of the right people. Two success factors were identified by several companies, showing their importance in the Colombian context and based on the local conditions: "reduction of turnover or continuity in the workforce" and "socialization of the results of the LC application". In the perspective of future works, this study can be extended to identify structural aspects to assess maturity in the LC application in construction projects.

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LEAN DIAGNOSIS FOR CHILEAN CONSTRUCTION INDUSTRY: TOWARDS MORE SUSTAINABLE LEAN PRACTICES AND TOOLS

José L. Salvatierra[1], Luis F. Alarcón[2], Angela López[3] and Ximena Velásquez[4]

ABSTRACT

Construction companies face important challenges to implement and sustain Lean methods, and they need to periodically assess the state of their implementation efforts. This paper presents the results of a collaborative initiative from seven Chilean construction companies to diagnose the implementation state of some aspects of Lean organizations: Philosophy, Culture and Technology. The diagnosis was carried out using data from four different tools: interviews with managers, workshops with Last Planner implementers, visits to projects and planning meetings, and an organizational survey to validate previous results. Despite 90% of managers believe that Lean is central to enhancing their businesses, important barriers to sustain practices were detected such as Last Planner (LP), which was identified as a common tool among those companies. Thus, the most important aspects observed could be summarized as lack of certainty, lack of training, and very limited use of other tools; moreover, important differences were identified with regards to the level of LP implementations. The diagnosis is expected to constitute a base to generate improved company strategies to implement and sustain Lean construction practices, with emphasis in the development of people as a core of Lean organizations.

KEYWORDS

Continuous improvement, Last Planner System, Lean construction, Lookahead.

INTRODUCTION

Continuous improvement is promoted as a permanent practice for organizations working under a Lean approach. Hence, identifying the current problems in order to

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look for the best practices and sustaining them over time have become essential activities to achieve better results.

Different studies have been presented at the International Group for Lean Construction – IGLC -, which intended to evaluate the implementation states of Lean tools such as Last Planner System (LPS) and/or to identify cultural aspects to assess the maturity state of Lean organizations. Up to now, various barriers have been identified, helping both researchers and industry people to recognize the critical aspects to focus their efforts on solving these problems more proactively Viana et al., 2010; Hamzeh, 2011). One possible reason for the identified barriers is that the companies implement Lean tools only from an operational point of view, disregarding essential aspects such as a solid support base, a clear view of the future vision aligned with the companies' strategic objectives, and a more holistic approach (Barros and Alves, 2007). This is further combined with other common problems related to lack of knowledge (Viana et al., 2010.), lack of training (Brady, et al., 2009; Porwal, et al., 2010; Cerveró-Romero et al., 2013), education (Brady et al., 2009; Jara et al., 2009; Mossman, 2009) and lack of maturity in the organizations (Chesworth, London and Gajendran, 2010).

Changing traditions and culture seem to be prerequisites for implementing Lean in the Construction sector. That is why the development of implementation strategies and training at both organizational and project levels with strong leadership and commitments could be the most important steps for a successful, sustainable implementation over time.

Chile has been a pioneer country in the application of Lean Construction practices, which has given rise to the Building Excellence group of companies, which work collaboratively under the guidance of the Production Management Centre of the Catholic University of Chile (GEPUC) in various investigations in order to improve this field's performance. This paper presents a research called "Lean Tools Sustainable over Time," whose main objective was tackling the great concern among companies about making LPS a successful tool over time, avoiding the difficulties that ineffectiveness commonly causes as work develops. For this purpose, the first phase of the research consisted of a diagnosis attempting to identify the current state of the implementations and other aspects that may be related to Lean Construction (LC), whether belonging to these organizations' cultures or philosophies. It should be noted that the 10 companies participating in the research have LP as a common tool; therefore, the diagnosis activities are mostly focused on assessing this planning system.

LEAN CONSTRUCTION TRIANGLE ACCORDING TO GEPUC

Womack and Jones (2003) summarize Lean thinking in 5 key principles: Specifying value (according to the customer's perspective), Identifying the Value Chain (Value v/s No Value, Losses), Creating Continuous Flow, Pulling Production by the Customer, and Searching Perfection. In order to visualize the key aspects of Lean in the construction sector, GEPUC has suggested a triangle that graphically represents in its vertices three fundamental aspects for a global understanding: Philosophy, Culture and Technology and/or Tools (Figure 1). Thus, for diagnosis development these aspects were regarded as the starting point for viewing different aspects related to the sustainability of successful Lean Construction practices.

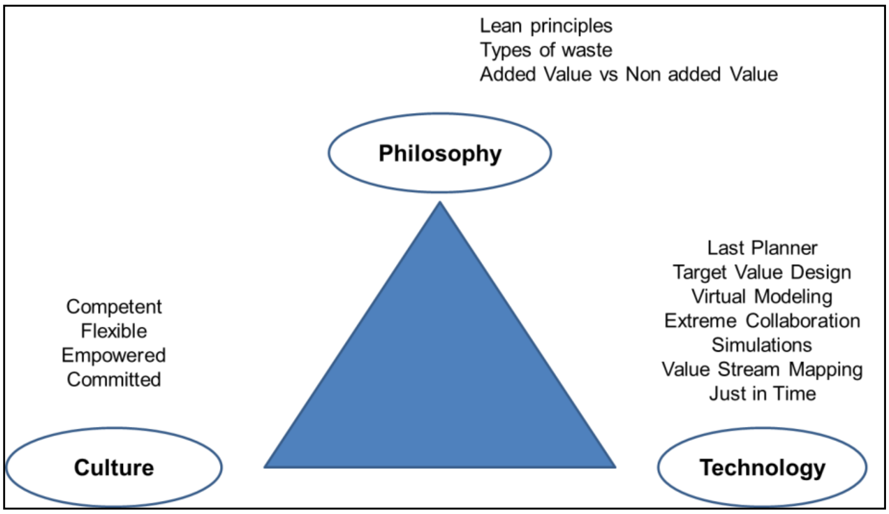

Figure 1: GEPUC's Lean Triangle (own elaboration).

METHODOLOGY

In order to define the current state of Lean implementation, considering that Last Planner is a common tool for the 10 participating companies, a diagnosis from August 2014 to January 2015 was carried out. In summary, data collection process includes four main steps summarized in Table 1.

Table 1: Data collection process

Stage	Objective	Participants	Description
Stage 1 (August, 2014): Management Interview.	Identifying involvement state from management on Lean operational issues.	31 participants: General Manager, Operations/Project/Technical Manager, Human Resources Manager, Implementers.	Ten structured interviews with the managers of organizations with an average duration of 2 hours were carried out. Open questions intended to learn about aspects such as reasons to implement Lean methods and resistance to change within organizations, whether the Lean perspective was a part of the training or induction processes of their workers, their workers' skills facilitating the development of their organizations, among others were asked.
Stage 2 (September, 2014): Last Planner Implementers Workshop.	Identifying experience in LPS implementation on-site.	25 LP implementers with 1 to 10 years experiences.	Two workshops were carried out with activities aimed at collecting information regarding issues related to the support from the organization, implemented strategies for success, leadership, barriers, among others.
Stage 3	Viewing the	On-site teams (Last	Eleven projects were visited,

(October to November 2014): On-site Visits	implementation, use of tools, and cultural aspects realities.	planners)	specifically their planning meetings. For data collection, the following three instruments were used:
	Validating the information obtained from management interviews and the implementers workshops.		Survey to all participants in the planning meeting. This tool was structured based on closed questions. Its aim was to collect information regarding: experience, culture, planning, standardization, transparency and continuous improvement.
			Planning practices checklist: This instrument was designed based on literature study, and it seeks to detect whether key issues are being addressed (e.g., Lookahead). Additionally, general aspects of culture, such as respect, leadership, and others were identified.
			On-site inspection checklist: With the objective of detecting Lean-related practices on-site, the use of tools was identified.
Stage 4 (December 2014 to January 2015): Massive, on-line surveys.	Contrasting obtained information from the earlier stages (based on the company's general view)	533 participants, including managers, administrators and foremen.	Seven on-line surveys consisting of 53 statements, with a Likert scale, which addressed the following dimensions: Teamwork, Capacity Development, Management Practices, Continuous Improvement, 5S, Communication, Understanding of Lean, Standardization, Value, Planning and Technology.

DIAGNOSIS RESULTS

The information obtained in steps 1, 2 and 3 allows us to identify organizational elements or aspects that are considered barriers or that have contributed to support Lean practices within organizations. It should be noted that in step two the assessments made by experts are also considered.

Stage 1- According to the interviewed managers' opinions, the main factors are the following:

- Factors identified as barriers to support Lean Practices:
    - Resistance to change: Lack of certainty about the usefulness of Lean tools persists on an organizational level, which is even greater on senior professionals whose previous experiences are not based on this new approach. Moreover, loss of motivation is considered a factor influencing the change of approach at the level of organizations
    - Lack of Training: Poor preparation of people is recognized. Accordingly, seven of the ten companies have not added any kinds of

skills to their staff selection under a Lean focus, and only 50% of the 31 interviewed managers have participated in inductions or trainings related to this. .
    - Leadership: According to the managers interviewed, in order to find key characters influencing the companies' transformation, it is difficult to have people with adequate leadership skills.
    - Industry features: Aspects related to the industry's distinctive features such as high staff turnover, lack of continuous monitoring of new practices (return to traditional procedure to face emergencies) and coordination difficult due to a large number of subcontractors working simultaneously are recognized.
- Success to maintain Lean Practices:
    - Certainty: According to those interviewed, in order to sustain the success of Lean tools over time there must be organizational certainty, and senior managers must promote their use. Significantly, 90% of the interviewed agrees that Lean methods are crucial to the growth of the company, and they should not be seen as complementary.

Stage 2 – According to the Last Planner Implementers, the following aspects can be identified:

- Barriers to maintain Lean Practices:
    - Lack of alignment: Within organizations there is no unanimous perception of Lean philosophy, but an increased understanding of the tool as an instrument, e.g., "Lean Philosophy is the same as Last Planner." Additionally, it is noted that if the company's areas are not aligned based on a common philosophy or goal, there will always be conflicts affecting the sustainability of the practices.
    - Resistance to change: People's ages and the organization's ineffective internal communication channels.
- Success to maintain Lean Practices:
    - Certainty: According to the opinions of workshops participants, the key success factor of the tools is internal certainty about their existence regarding their usefulness. In most cases it is recognized that LP has been the only tool used; in this sense, few organizations have promoted the use of other tools such as 5S and VSM.

Stage 3 - Site Visits allow identifying the following key elements:

- Barriers to maintain Lean Practices:
    - Lack of social skills: According to experts' assessment, Commitment and Motivation exhibit the lowest rates (Figure 2). These results come from the assessment carried out at the LP meeting, in which not only aspects related to the tool itself were evaluated, but also those related to the skills of those people conducting these meetings.
    - Lack of key elements of LPS: Table 2 shows that indicators such as Percent Constraint Removed (PCR) and Executable Work Inventory (EWI) are observed only in 2 and 3 projects respectively. Therefore, the potential benefit of Weekly Work Planning and Short Term Planning in uncertainty management is being wasted. It is important to

note that despite the Causes of Non-Completion (CNC) management in 7 of the 11 projects visited (64%), planning meetings do not lead to find the root causes of the problems. Additionally, it is possible to identify that only 36% of Last Planners analyse their own causes of noncompliance.

  - Visual management: According to experts' criteria, some elements that may be affecting the sustained success of Lean practices is the limited use of visual management tools. Thus, they have been incorporated in less than half of the projects, and the way it has been observed is through panels, dynamic displays, and graphics to present production results, among others.
  - Lack of tools: Tools related to continuous improvement such as Ishikawa Diagram, among others, were not identified. On the other hand, the use of management support tools, such as A3, BIM, VSM and Kitting, as well as 6S's approach on-site is observed in a small number of projects (Figure 3).

- Success to maintain Lean Practices:
  - Social skills: According to the experts' criteria, Leadership and Respect have the highest rates evaluated [5] (Figure 2). Both are considered key factors for the sustained success of the LC-associated practices.. Regarding the on-site survey, all aspects are largely well evaluated by the participants of the meeting, reaching approvals of over 90% (Figure 4).

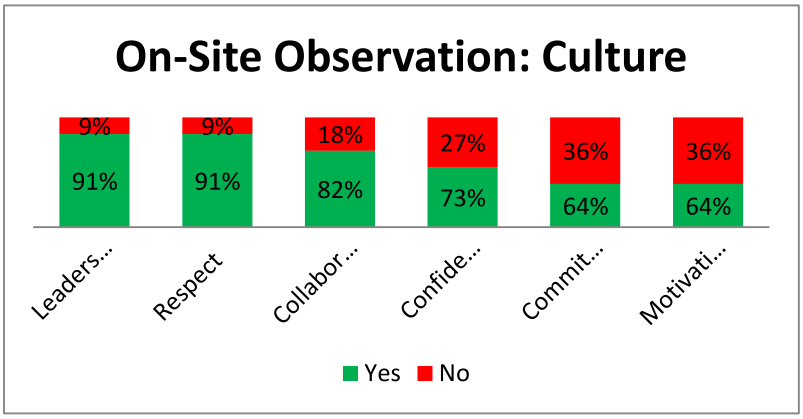

Figure 2: Culture: on-site observation (own elaboration).

[5] Note that these aspects were evaluated based on the perceptions of consulting engineers and psychologists with training and experience in Lean Construction

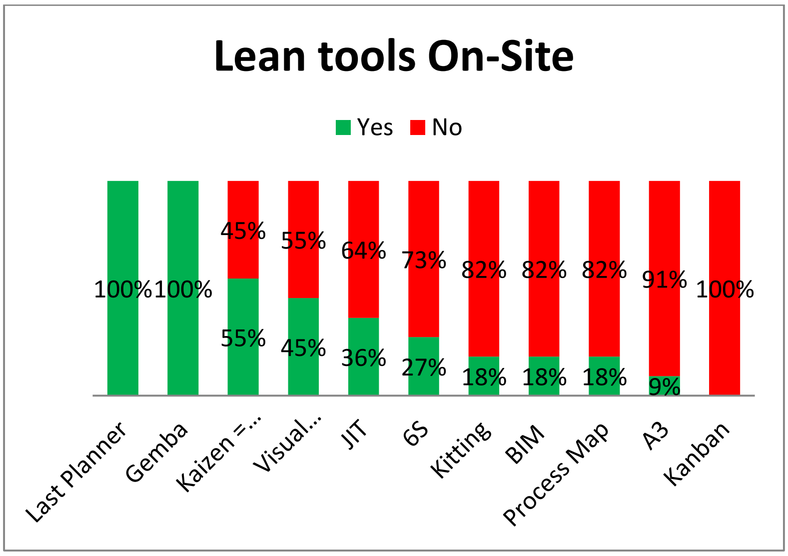

Figure 3: Lean Tools On-Site (own elaboration).

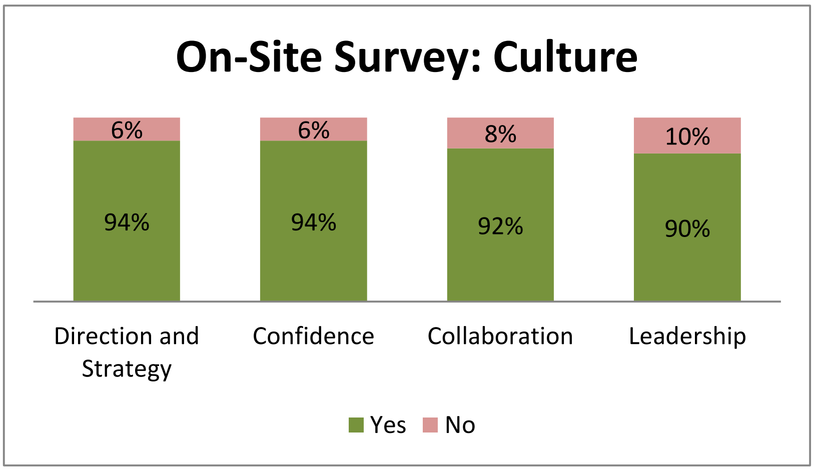

Figure 4: Culture: on-site survey (own elaboration)

The final stage includes the organization's global view, represented by opinions from the management departments to those of the on-site technical offices.

Stage 4 - Organizational surveys: The lowest dimensions correspond to Skills Development, Lean Understanding and Planning. Note that these dimensions involve the following aspects.

- Skills Development: Selection, Induction and Training.
- Lean Understanding: Lean Concepts and tools, advantages of this approach, and aspects of the philosophy.
- Planning: Involving, compromise, transparency and continuous improvement of planning processes.

On the contrary, the highest measured dimensions according to the organization's global view correspond to:

- Teamwork: Incentives, common objectives, awareness of colleagues' skills, internal client.

- Culture: Encompassing aspects such as continuous improvement, respect, motivation and leadership.

General results are shown on Figure 5.

Table 2: LPS Implementation Level

Phase	Practice	Average
Master Plan	Master Plan – Phases	100%
	Interactive Planning	27%
Intermediate Plan	Intermediate-Lookahead Plan	91%
	Percent Constraint Removed (PCR)	27%
	Executable Work Inventory (EWI)	36%
Weekly Plan	Weekly Plan	100%
	Percentage of Plans Completed (PPC)	82%
	Causes of Non-Completion (CNC)	64%
	CNC Solution	36%
	Weekly Meeting	100%
General	Standardization of Processes	9%
	Visual Information	36%
	Average Lookahead (weeks)	3.7

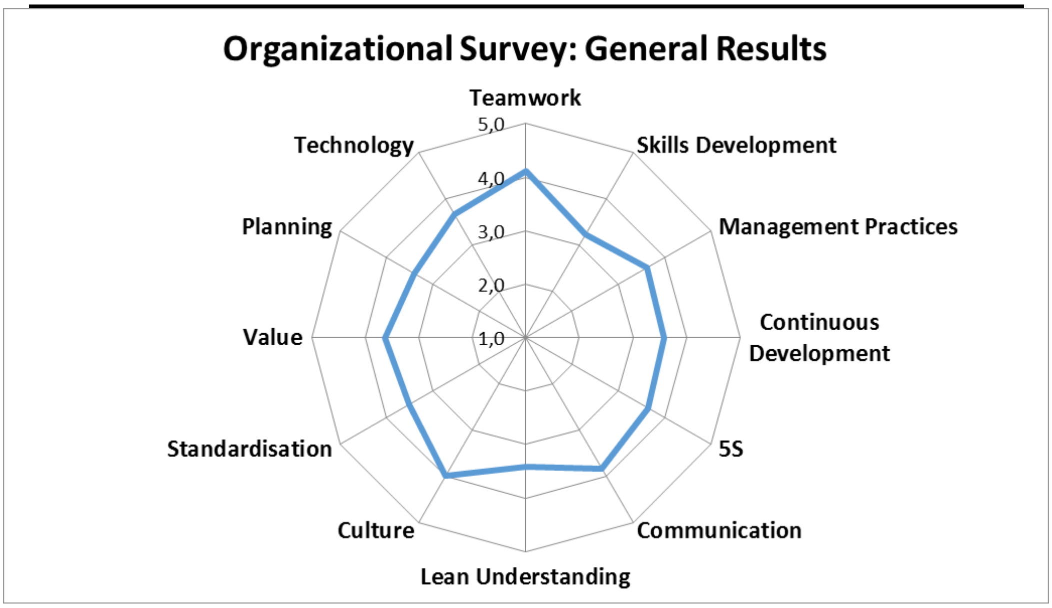

Figure 5: Organizational Survey: General Results (own elaboration).

CONCLUSIONS

The results of the diagnosis presented in this study have identified aspects related to sustainability practices related to Lean in a group of 10 Chilean construction companies belonging to the "Building Excellence" Collaborative Group of GEPUC.

The results show that although most managers considered Lean philosophy as central to the development of their companies, the skills of their employees have not been adjusted to this new thinking up to date; also, there is no continuous training. Both aspects are considered important elements to create culture inside organizations. At present, there are no standardized HR management practices in organizations, with no continuous training models or programs to transversally integrate the philosophy. This highlights the lack of alignment of the efforts in implementations with the strategy of these organizations. Important aspects related to change resistance within organizations were identified. Some of them are related to the industry's characteristics, such as high staff turnover and coordination difficulties due to the large number of parties involved in the same project. Others are related to the difficulty of teaching new approaches to seniors.

With regards to the use of technologies and/or tools,, the employment of other commonly used tools by organizations, apart from Last Planner, both on-site and at headquarters, cannot be broadly identified, which can also be considered an important aspect when assuring success of Lean practices over time.

Regarding the particular case of LP, it is confirmed that despite the efforts made to date, some fundamental aspects such as analysis of reasons for incomplete assignments, constraint management, among others are still on a basic level. Accordingly, when analysing projects of the same company, significant variations were observed. It is also concluded that it is impossible to view a clear alignment of the companies with LC approach. Note that in the organizational survey the planning dimension was one of the most poorly evaluated.. An important aspect to note is that leadership, which is recognized as a key factor for the success of Last Planner, proves to be a well-assessed aspect by the expert evaluators of the planning meetings. On the other hand, the organizational survey showed that aspects related to teamwork are well perceived within organizations.

. It is worth noticing that the most relevant aspect is certainty when considering Lean Construction as a valid approach for organizations. Hence, there is agreement that the strategy should be aimed at demonstrating the utility with tangible results, effective training, and empowerment with the equipment.

Finally, note that the second stage of this research will be aimed at developing a development model for people. Thus, it will be necessary to study competence and role gaps for a "lean profile" which supports people management departments. The idea is that these profiles consider key aspects to be included in induction programs, which will be considered in the organizations' performance evaluations.

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A MEASUREMENT MODEL FOR LEAN CONSTRUCTION MATURITY

Claus Nesensohn[1], Dave Bryde[2], and Christine Pasquire[3]

ABSTRACT

At IGLC 2014 a Lean Construction Maturity Model (LCMM) was introduced. The LCMM comprises five maturity levels, eleven Key Attributes (KAs), and sixty defined Behaviours, Goals & Practices (BG&Ps); with 75 Ideal Statements to measure organisational maturity in the adoption of LC. Whilst recognizing that it is not necessary or desirable to derive a narrow and precise definition of LC – indeed there are many different ways in which an organisation may apply LC principles in practice, a degree of measurement is required in order to assess and where appropriate improve current practices. In the words of a well-known maxim: what get measured gets managed. This paper describes the research method used to validate the LCMM, which was done using focus groups, and presents the validated model. It also contributes to our understanding of the usefulness of measuring approaches to LC by using the LCMM to illustrate differentiating characteristics between organisations that are "mature" and "immature" in LC.

KEYWORDS

Lean construction, continuous improvement, transformation, maturity models, focus groups.

INTRODUCTION

Lean Construction's (LC) growing popularity is even acknowledged by those who question the applicability of Lean to the construction sector (Green et al. 2008). Green draws our attention to his critical definition of LC as a "complex cocktail of ideas" (Green, 2002, p. 148). This notion of a complex cocktail actually has its merits in that LC is not pigeonholed as a narrow and prescriptive management technique applicable to the construction context. The notion also stresses the inclusive nature of the LC movement. Yet the danger of too much pluralism in the discipline of LC is that it leads to fragmentation and, hence, it opens LC to critics who refer to it as a somewhat nebulous concept: the negative connotations of a "complex cocktail" of

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ideas. If it is not clear what constitutes LC, as it is too complex a cocktail, then it will be difficult to both introduce and to improve LC practices in an organisation.

Since Maturity Models (MM) facilitate an organisational assessment of its current maturity (Pennypacker, 2005; Perkins, et al. 2010a; Perkins et al. 2010b), which can also be described as measuring against a defined reference point (MM) (Cooke-Davies, 2007), such an MM for LC would describe what a more mature organisation looks like, in terms of LC. Furthermore such organizational assessments of maturity can provide a number of benefits, such as: guidance for the transformation with information about strengths and weaknesses (Perkins, et al. 2010a); awareness of the current state and improvement requirements (Wendler, 2012); support in implementing change in a systematic and well-directed way (Cooke-Davies, 2007); and an enabler to a sustained embedding of business processes (Eadie, et al., 2011).

To date MM-related research and conceptual developments has focused predominantly on the software engineering industry (Nesensohn, et al., 2013a). This work has resulted in the creation of the Capability Maturity Model Integrated (CMMI) which it is claimed is the most well-known (Wendler, 2012) and the most widely adopted MM (Eadie, et al., 2011). However the tried and tested MMs, such as the CMMI, are generic and they do not provide the necessary data i.e. the specific attributes and processes which are associated with maturity in terms of LC. Yet existing MMs such as the CMMI have potential in providing a starting point for developing an MM for Lean (Nightingale and Mize, 2002). Furthermore, Nesensohn et al. (2013a) call for further work to develop such a model for LC which is grounded in empirical study. This paper responds to this call by presenting a validated model, called the Lean Construction Maturity Model (LCMM) which provides a model for assessing LC maturity that is, in part, informed by the approach taken by the CMMI. This model enables organisations to assess their current LC maturity and can be used to differentiate between organizational immaturity and maturity in terms of LC. The paper specifically describes the research method used to validate the LCMM, which was done using focus groups, and presents the validated model – which was first introduced in a paper presented at IGLC 2014. A second goal of the paper is to contribute to our understanding of how the measurement of organizational maturity in LC could be undertaken, by using the LCMM to illustrate differentiating characteristics between organisations “mature” and “immature” in LC.

RESEARCH METHOD FOR VALIDATING THE MODEL

The original research utilized a mixed method design to develop the LCMM. This enabled a more complete picture of human behaviour and experience (Morse, 2003) which was important as the key informants for the original research have practiced LC over time and hence attach meaning to the phenomenon of “LC maturity” and to the maturation of LC within organisations. Its primary research design method was a phenomenological approach taken involving focus groups (FG) with semi-structured interviews as supplementary components. Since this paper is focusing on the validation of the developed LCMM we refer here to the detailed development of the LCMM in previous publications such as, (Nesensohn, 2014, Nesensohn, et al., 2014a). To validate the LCMM it was necessary to undertake another empirical study, which made use of experts (Ricardo, et al., 2014) who were involved in the data collection stage of the original research, to ensure the interpretation of the data was accurate -

this validation strategy is known as member checks. The validation involved interviews with three experts followed by one FG with further three experts. All of these participants were LC experts involved in Lean projects for between 3 and 19 years. The sample comprised LC experts working as contractors or in engineering companies, or as a consultant.

The interviews took place following the FG member check. The interviews had an approximate duration of one hour; and the participants received a document, which described the developed model and its elements, with several explanatory figures, prior to the interviews. In the interviews the participants were asked about the completeness and accuracy of the previously collected data and if there was anything missing in the model. They were also asked for their views on the practical suitability of this model.

The FG member check was chosen to enhance accuracy and correctness of the findings (developed model) and their interpretation (Creswell, 2013). This FG was conducted similar to those conducted as part of the primary data collection. Hence this validation FG had the advantage of including an observer who provided a guideline. Contemporaneous notes were recorded on flipcharts and at the end of the FG the participants verified the accuracy of these notes.

The developed model was presented to the FG participants. To increase the credibility of the validation the model was presented in sections rather than as a whole. The sections were: model structure; top layer; and each single factor including its Key Attributes, Behaviours, Goals and Practices (BG&Ps), as well as Ideal Statements. Finally, the maturity levels were considered, including the practitioner-led assessment. This enabled a focus on all elements of the model without getting too distracted by the detail of each individual component. The presentation took approximately thirty minutes to complete. It used several figures and hand-outs to enable participants to gain a fast and complete understanding of the model. Following this the participants were asked for each section [outlined above]: *is this valid from your point of view?* The overall response to this question for each section was very positive. All participants agreed that the LCMM with its factors, Key Attributes, BG&Ps, and Ideal Statements was valid.

Similar to the member check with the individual interviews, it was important to seek opinions on the practicability and suitability of the LCMM in practice. Hence the participants were asked: *what are your views on the practical implementation of the LCMM?* In response to this question all participants agreed that they see the model as suitable for practice. In addition, the participants agreed that the LCMM offers a good methodology and diagnostic tool for an organisation to get from A to B in a Lean Journey. Two participants indicated that it seemed practical to them that the LCMM enables one to see where they are. You look at the overall picture of your maturity, you see where your gaps are, and you are able to prioritise where you want to improve in terms of Lean maturity. Furthermore, one participant stated that the model is a very good tool to start a discussion about LC within the organisation. Moreover, all participants saw this model as an enabler for organisations to create a plan to achieve more maturity in LC. Although the participants indicated that it is quite possible that the prioritisation needs some more data analysis to identify those areas that are most important to the specific organisation.

The most striking result to emerge from the validation is that all participants agreed with one individual who stated that the LCMM *"really deconstructs [simplifies] and explains Lean in a better way [than] something [we] had before".* In addition, the FG believed that the LCMM includes a lot of elements which explain, in the words of one participant, the concept and philosophy in *"a very good way"*. Other responses to this question focused on the assessment of LC using the LCMM. It was agreed that assessors using the LCMM need to know what they are looking for, so a real understanding is needed in order to undertake the assessment process. Further, it was felt that the LCMM would be useful for consultants who would be able to use it to know what level 4 looks like. Both findings clearly highlight the fact that it is important to assess LC maturity through a practitioner-led assessment, rather than using the LCMM as a self-assessment tool. This is because the assessor really must know the LCMM in detail and be an expert in LC.

Finally, two participants indicated that despite the agreed practical suitability of the LCMM there are possible barriers to its use. For instance, it was stated *"we need to generate a need and a want for this LCMM in the industry"*. Another participant stated that a lack of *"leadership"* is a main barrier, which would need breaking down. The validated LCMM is presented in next section.

THE VALIDATED LCMM

Eleven Key Attributes (KAs) demonstrate the first major element of the LCMM – see Table 1. These key attributes are organised through 6 high-level factors: Philosophy, Leadership, Learning, People, Processes & System and Outcomes & Outputs. The factors represent an overall flow and a direction from left to right. This need for flow was a major finding from the final validation stage of the research process. To achieve this flow it was decided to integrate the framework from the EFQM Excellence Model as the top layer for the LCMM (EFQM, 2012). Hence having such a top layer, with defined factors, provides a unique element for the LCMM. This is shown in Figure 1.

Behaviours, Goals & Practices (BG&P) were created which are distinguished as follows:

- a *behaviour* associated with LC maturity
- a *goal* in the form of the [desired] characteristics of a more mature organisation
- a *practice* which is considered to be important for LC maturity.

Sixty BG&Ps were defined, each comprising of a name, as an identifying component, and at least one Ideal Statement per component - which must be met for an organisation to satisfy the related Key Attribute for a given maturity level. These Ideal Statements play a vital role in measuring the maturity of LC.

Table 1: The Eleven Key Attributes (KAs)

Key Attributes/KA	Purpose of KAs
1. Lean Leadership	The purpose of Lean Leadership is to establish and maintain leaders who actively encourage and drive individuals and teams towards more maturity in LC.
2. Customer focus	The purpose of Customer Focus is to establish and maintain an understanding and focus on both internal and external customer value
3. Way of Thinking	The purpose of Way of Thinking is to establish and maintain a holistic approach of thinking that supports LC maturity.
4. Culture & Behaviour	The purpose of Competencies is to establish and maintain a foundation for individuals and teams to continuously improve the competencies required to drive the transformation towards LC.
5. Competencies	The purpose of Competencies is to establish and maintain a foundation for individuals and teams to continuously improve the competencies required to drive the transformation towards LC.
6. Improvement Enablers	The purpose of Improvement Enablers is to make it possible for the people and the organisation to improve their LC maturity
7. Processes & Tools	The purpose of Processes & Tools is to establish and maintain an improvement of the processes that deliver the ultimate value.
8. Change	The purpose of Change is to establish and maintain a context by which the change towards LC is intrinsic.
9. Work Environment	The purpose of Work Environment is to establish and maintain working conditions that encourage individuals and teams.
10. Business Results	The purpose of Business Results is to enhance the alignment of performance criteria with the contribution of individuals and teams.
11. Learning and Competency Development	The purpose of Learning and Competency Development is to insure that individuals, teams and the organisation are constantly learning to enhance their skills, knowledge and competencies.

THE LCMM AND “MATURE” V “IMMATURE” ORGANIZATIONS

The main applicability of the LCMM for LC maturity within the construction sector is for organisations which are either planning to further embed LC in their organisation or those who are starting upon their Lean journey. This includes organisations such as: clients, contractors, and sub-contractors. Organisations like architects and engineers may also benefit from utilising the LCMM. The results of the validation process indicated that the LCMM enables organisations to get a systemic and holistic overview of the current state of maturity in LC. Therefore the model provides an explanation of the differences between mature and immature organisations in terms of LC.

More mature organisations are able to identify their strengths and weaknesses in terms of LC implementation. Hence they have a process or model in place which enables them to assess and illustrate gaps and areas with higher levels of maturity in relation to some aspect of LC. More mature organisations utilise data which they have gathered to guide their decisions and support their strategy in the prioritising of planned improvement actions towards greater maturity. Since the validation process suggested that the LCMM provides organisations with such guidance for their transformation, this data can be used to develop targeted interventions and workshops aimed at improving the maturity of a particular BG&P.

More mature organisations have a common language in terms of their Lean journey, whereas immature organisations are characterised with the use of buzzwords and unclear definitions of those words. So individuals have difficulties in understand the meaning of the specific phrases, terms and words, which works against the establishment of shared meaning and commonly agreed methods to achieve LC goals and strategies. The LCMM addresses some of these problems, helping to establish a common language and raise shared awareness of the LC philosophy and its associated concepts within an organisation.

LIMITATIONS OF THE MODEL

All aspects of the LCMM might not be easily transferable to the context of short-term construction projects and to temporary organisations, because the value generated through the LCMM, which is likely to be realised over a relatively long time-frame, could be difficult justify from a short-term financial cost-benefit analysis perspective. A further limitation to applying the LCMM is the fact that the assessors need to know the model and LC very well in order to achieve the desired results. This adds to the cost of applying the model i.e. training assessors and paying for assessments by outside experts. A final limitation of the LCMM is the risk of its inappropriate use as an organisational assessment tool. Since the Key Attribute “Culture & Behaviour” of the LCMM seeks to establish trust and collaboration, it would be a totally inappropriate use of the model to use it as a method to blame other divisions or parts of the organisation for some perceived failure of LC implementation. This is because a blame culture is incompatible with the underpinning philosophy of Lean and is not conducive to one of its key concepts, namely continuous improvement.

CONCLUSIONS

This paper has presented the final version of the LCMM, which has been validated through three individual interviews and a FG with three participants. This validation confirmed the applicability of its overall structure and constituent elements, its usability to practice, implications of its use and possible limitations. The LCMM enables an organisation to gain a systemic and holistic overview of their current state of maturity in LC. It supports them in planning and directing their transformation towards greater maturity in LC. The validation confirmed the suitability of the LCMM as an appropriate method to measure the current state of maturity and to support organisations in planning and directing their transformation towards greater LC maturity. A contribution to knowledge of the LCMM is the conceptualisation of LC presented in the model. Hence, a common understanding of Lean concepts and the LC philosophy adopted by a specific organisation and its individuals can be achieved by interacting with the model. The deployment of the LCMM can stimulate discussions about LC within an organisation, which are necessary to raise awareness and energize activities to either start or continue on an LC journey. In terms of using the LCMM it is stressed that it needs the involvement of the right person to oversee its implementation and that this person needs a deep understanding of the model and of LC. To finally conclude, the LCMM provides a unique opportunity to improve the LC capability in organisations. As well as helping to increase LC maturity it provides a tool for aligning and measuring sought after improvements in the management-related activities of organisations in the construction industry.

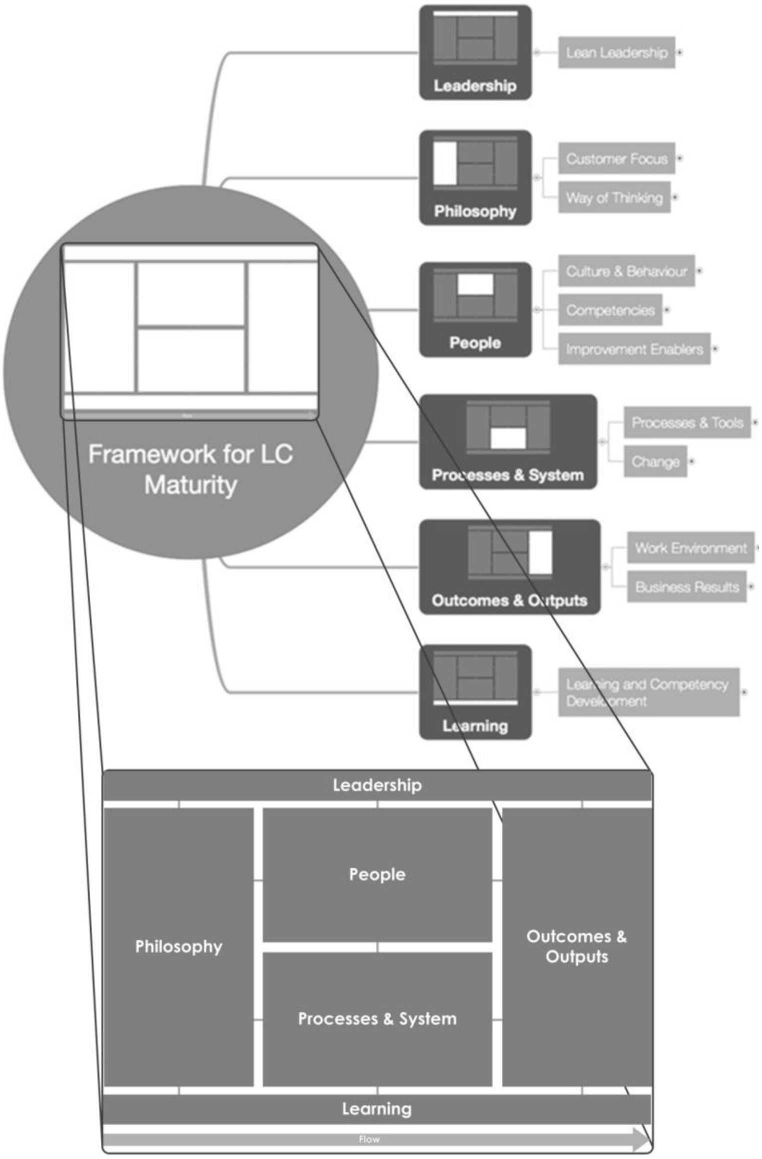

Figure 1: The LCMM

FURTHER WORK

Increasing our knowledge about LC maturity and the ability to measure the current state of maturity, as well as supporting organisations around the world in their transformation towards greater maturity in LC, is vital. Thus, the outcome of this research, in the form of the LCMM, provides a solid foundation for further investigation into the application of the concept of MMs to LC. Further work needs to be done to test and strengthen the whole range of propose benefits of MMs in general and the LCMM in particular. This should be considered within a case study-driven research strategy. Additionally the generalisation of the emergent elements of LC maturity as well as the 11 Key Attributes of LC – articulated in the LCMM, can be confirmed or disconfirmed through further empirical evidence. For example, the LCMM may be applicable to consultancies/service organisations in the construction industry, such as principal quantity surveyors, but this potential applicability needs to be further investigated.

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REDUCING VARIABILITY OF A VALUABLE CONSTRUCTION INPUT: SUBCONTRACTORS

Matt Stevens[1]

ABSTRACT

Subcontractors are critical to the U.S. construction industry. They are used by general contractors (GC) to preform a majority of work. Subcontractors safely install components specified, in the time needed, and at a competitive cost. It appears that some misalignment of Lean Construction (LC) methodologies and realities of managing subcontractors. More research is needed to address this largest input in most projects. Currently, LC suffers from low adoption. Looking ahead to the next 3 years, all contractors plan adoption at the same low rate. This paper will review an action research project and its outcomes which involved a GC and its subcontractors over three years of projects.

KEYWORDS

Lean Construction, LC, production, productivity, variability, subcontractor, PDCA

INTRODUCTION

Subcontractors build specified project work typically at the direction of general contractors that are guided by project plans, specifications, local regulations and demands by the construction services buyer. Subcontractor's actions mostly determine critical outcomes such as safety, cost, schedule and quality. However, more research is needed to understand and improve these critical partners in the construction process.

A recent study concludes a low contractor adoption rate presently and projected in the United States. It may signal a need to reassess the interpretation and application of Toyota's Production System (TPS) to the U. S. Construction Industry.

This paper's aim is to suggest modifications to Lean Construction (LC) Methodology that tailor it more closely to the use of construction subcontractors. Additionally, an analysis is offered of modified Lean processes that appear to cause efficiency gains in study of a General Contractor (GC) and it subcontractors over three years of projects.

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LITERATURE REVIEW

SUBCONTRACTORS AND LC

The contracting industry's combination of peculiarities is unique (Hillebrandt, 1984). For subcontractors, the process of construction may consist of mostly short term employed persons on a temporary team building a project that involves hundreds of sequenced inputs. These inputs, such as information, money, planning, material, equipment and craft workers are iterative. At the same time, each participating company has to manage other ongoing unique projects and these same inputs (Sacks, 2004).

LC has been influenced by a machine environment in a static production setting that characterizes the Toyota Production System, TPS. People operating stationary machines are generally sheltered from the weather. The human element has been assumed as predictable and loyal due to Japan's cultural norms and lifetime employment guarantees (Green, 2002). Many concerns about the application of Lean are based on contextual differences between manufacturing and construction (Jørgensen and Emmitt, 2008)

A recent industry study found only 28% of participating construction firms have adopted at least one Lean Construction (LC) practice. Of those who implemented a single practice, 36% adopted pull planning which is one of five subsets of the Last Planner System© (LPS). LPS is the LC community's most prominent process. Although LC research is more complete than ever and prominent projects have been performed with LC methodology, the future is not brighter. Of those classified as familiar with LC, but have not implemented practices, the same low percentage of contractors (28%) plan to implement LC, in any form, in years 2014 – 16 (McGraw-Hill, 2013). Although, no reasons were given for low adoption, it can be assumed that LC is perceived by GCs and Subcontractors as having low improvement value as Green suggests (2002).

Non-LC researchers outlined several fundamental practices critical to managing construction subcontractors. These include several that are in the spirit of LC and others that are opposite of LC's instruction. Those in agreement a) Help subcontractors do timely work by providing assistance and resources as appropriate and b) Walk the job frequently; get to know the subcontractor's workers and offer assistance as appropriate. Those in conflict a) Meet regularly with subcontractor's senior supervisor individually b) Enforce the contract (Thomas and Flynn, 2011).

Edwards Deming, the father of Total Quality Management - the pre-cursor to Lean, is quoted, "Uncontrolled variation is the enemy of quality". Additionally, Plan-Do-Check-Act (PDCA) is a standard 4 step quality process created by Deming has been confirmed as efficient.

Shigeo Shingo, co-developer of Lean, stated that lack of discipline in planning and execution will weaken attempts to improve. Planning is described as "wait to start and then go faster" (Alarcón, 1997). There is a consensus that formalizing pre-construction planning for all contractors regardless of hierarchical level would improve outcomes including productivity and project efficiency (Menches, et al., 2008)

Lean's Heijunka concept teaches levelling work in process which helps control variation and thus, limits a source of waste. A company (manufacturing or construction) that produces steadily and can keep focus on improvement and ultimately, perfection. This leads to more customer satisfaction, repeat business, and predictable revenue. Empirically, there is a positive correlation in construction between the number of client contracts and the amount of variability (Ko, 2010)

First order results measure inputs placed into the production process. Examples of primary activities are gathering extensive information, planning or compliance to processes. First order activities directly influence second order results which are outcomes such as productivity, schedule adherence or profit. Schonberger stresses the importance of both first and second order (1996).

LC has largely ignored the professional nature and availability challenges of first line field employees and managers. These people may be seen as inputs and not critical enablers of the construction process in terms of safety, cost, schedule and quality (Green, 1999). Subcontractors represent the majority of first line employees and managers on most construction projects.

Koskela's updated flow theory includes labor input, but not ongoing worker availability during construction (Bertelsen, et al., 2006). This lack of specificity is understandable in an orthodox adoption of Lean. In manufacturing, there is only one place for worker to be: their factory station. In contrast, construction subcontractor front line employee could be working in one of several on-going projects. Some argue that the Toyota Production System (TPS) is not the starting point of LC, but Koskela's theory (Ballard et al., 2001).

TPS is largely enabled by machines, whereas construction is not. In LC, the human element is the most variable of all inputs. Each craftsperson, laborer, and equipment operator perform differently in quality and quantity of work produced. This means variability of input and may mean significant effort should be taken in leading and managing this factor.

One standard lesson of LC has been the "parade of trades". This classroom exercise is illustrative of a major issue of general contractor's use of subcontractors in a majority of building and infrastructure projects. One of its lessons is the effect of discontinuous flow. The result is a cascading effect of a subcontractor's superior or poor performance on subsequent activities on the project schedule. This includes occurrences of (unplanned) high production and the subsequent unmanned space showing production opportunity lost.

LC's standard planning process is the Last Planner System (LPS) which is collaborative, commitment-based planning system that integrates pull planning, make-ready, and look-ahead planning with constraint analysis, weekly work planning based upon reliable promises, and learning based upon analysis of Percent Plan Complete (PPC) and reasons for variance. It requires the subcontractor's on-site supervisor promise to complete work and to keep the promise reliably.

Work is made ready by creating a look-ahead schedule of the upcoming activities and performing constraints analysis. If an upcoming activity has a constraint, then that constraint needs to be identified and solved proactively in order to eliminate impacts to the current schedule (Koskela, 1999).

Front line field managers do not determine the quantity and quality of field workers working on site. Typically, workforce coordination is managed by an executive in the home office. The workforce (and other resources) is shared with other projects and their flow is affected by the sequencing of all the subcontractor's projects (Sacks, 2004). By LPS's design, this executive's involvement is minimized.

It appears that PPC have led to conservative work commitments (Salem, et al., 2005). In most construction contracts, physical progress determines billing. Under LPS, there may be conflicting incentives for the last planning person a) under-promising due to fear of underperforming per cent plan complete while b) maximizing production to produce as much revenue as possible for their employer, the subcontractor. When a few tasks are completed earlier than promised and others are never promised but completed, may be a form of discontinuous flow and thus, inefficiency.

According the U.S government, its construction industry has a significant job hire and separation rate. If one calculates the annual number of hires and separations, adds them together, and divides this number into the total employment, the resultant is one measure of job turnover. Calculated on an annual basis for years 2004 and 2013, it is 86% and higher (JOLTS, 2014). In one's construction career it may not be a matter of if, but when a person may be released from employment.

This hire/separate/rehire cycle is in sharp contrast to relatively continuous employment as practiced by Toyota. We can assume from this measure that employment separations are part of the construction workforce's experience and expectations.

This seems to call into question the process of the Last Planner since it is partially predicated on the person closest to the work at the field level to promise and achieve their production goals. It appears this front line manager has an incentive to promise a less ambitious production target. If one under promises and over performs, then the "parade of trades" effect may lead to overproduction waste. In contrast, if one ambitiously promises, but breaks those promises consistently, waste results. Also, it may lead to GC and fellow subcontractor conflicts. This poor performance perception could result in an early layoff (and loss of personal income). So the field manager's incentive appears to under promise the next period's work achievement.

FOUR PRACTICES THAT CONTRIBUTE TO IMPROVED GC AND SUBCONTRACTOR PERFORMANCE

The four processes outlined below closely follow two of Lean's instructions 1) Plan-Do-Check-Act and 2) Limiting throughput so efficiency (and perfection) can be the focus. In the description below, each practice is tailored to the realities of construction contracting.

Planning

Planning is a well-accepted method of reducing variability by LC and other improvement methodologies. Its basis is the simple, but powerful idea of visualizing beforehand the enablers of production which has a positive effect on performance.

An extended pre-project period started immediately after the project is won allows for extensive understanding and planning to be done, but also an atmosphere of acclimation and collaboration. Since some subcontractor field personnel may be newly hired or re-hired, a lengthy pre-project planning phase should familiarize each person to the culture and demands of the project.

Compliance Monitoring to Processes

Efficient processes only are valuable if they are executed. The level of compliance by those who build and manage largely determines the level of outcome as shown in the Case Study contained herein. One critical role of construction executives is to set expectations then inspect compliance to company processes on a continuous basis.

The most effective method for compliance measurement is a virtual one (intranet based). It allows instant updating and measurement.

Measuring Results

Construction results matter greatly in construction. The client is contracting for finished product and not the processes or people involved. Results have to be measured during all phases of the GCs contract. All contractors measure project results even if intuitively and, if deficient, address it with internal and external parties.

Levelling the Amount of Revenue

Winning projects more often is attractive since it increases revenue. Limiting the amount of required work means that estimators and business development personnel may be assigned other tasks at times include cost analysis and project administration.

CASE STUDY OF A U.S. GENERAL CONTRACTOR

The researcher was engaged from 2012 to 2015 as a management advisor by a $30 million general construction contractor (GCC) based in the United States. The firm, founded in 2008, pursued work mostly related to U.S. government needs. The major focus of the advising and training was to transform the firm to a more efficient one. The approach taken was for the researcher to assess practices currently in use, use practices confirmed by research and experience would align with the company characteristics. LC was a strong, but not total influence on thinking. Individual coaching of key employees was part of the process. Online courses allowed for continuing education of management and staff.

Projects completed by GCC (see Figure 1) show a diversity of general contracting challenges including Design Build, Hard Bid, New Construction, Refurbishment, Demolition, Building, Civil and Marine Work with completion times of three months to over a year. Locations were isolated from population centers and the general conditions amenities were modest due to market characteristics.

The company adopted, trained and implemented the following processes which were formalized and implemented in 2013.

Figure 1 shows a significant improvement over 3 years. For clarity, the first five and last five projects represent before and after adoption fairly accurately. Obviously, higher adherence to efficient processes is correlated to improved outcomes. The first five's unweighted outcomes were average project profit decreased (-81.69%) while exceeding the schedule (18.92%) than originally planned from lower compliance to processes (29%). Interestingly, the last five project's results were more variable as a percentage; average project profit improved (48.68%) over the baseline estimate while shortening the baseline schedule (-28.78%) with a higher compliance to processes (92%). From a cash flow basis, gross profit dollars earned increased on a weekly basis from project estimate. In the researcher's experience these are important outcomes to share with construction contractors if adoption of a new methodology is to increase.

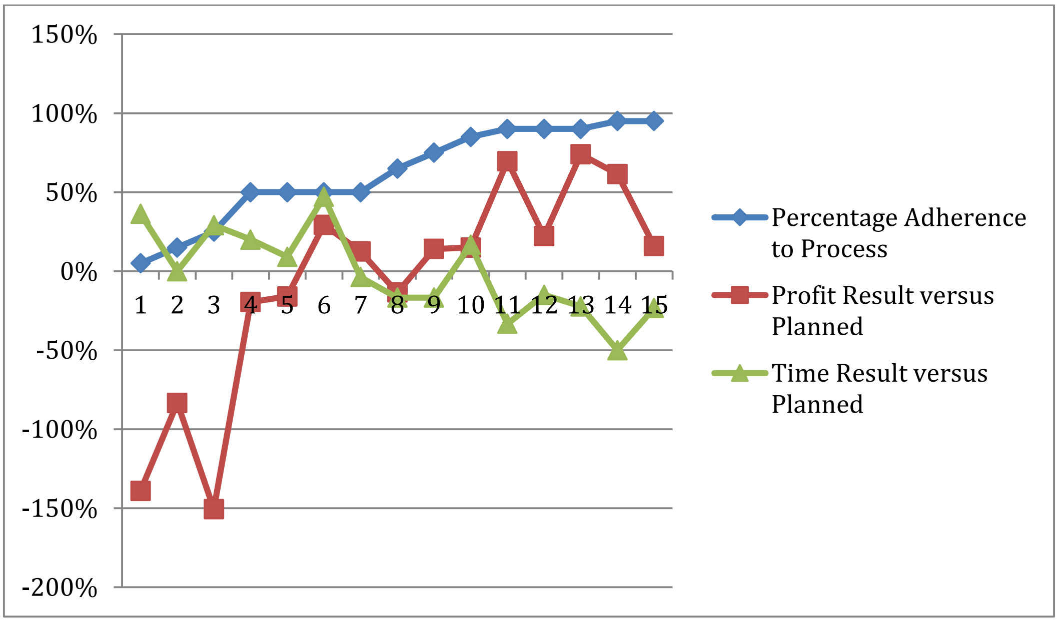

Figure 1: Company Furnished Data of Completed Projects Closed from 2012 to 2014 in Sequential Order Measuring Process Compliance, Cost and Schedule Results.

GCC made the following improvements or refinements to its existing processes. The four listed below were viewed as significant enablers of its improvement program.

Formalized pre-construction and pre-task planning

- Teams sought extensive project information and filled in a preconstruction checklist containing numerous critical items. It assigned specific personnel with responsibility and required timelines. The list was updated weekly with percentage complete for review by Project Manager (PM) and Senior Vice President (SVP) of firm.
- Subcontractor pre-coordination meetings were held with GCC site personnel with minutes and action planning two to four weeks before subcontractor is required to mobilize. Mandatory review of material and man power readiness including a check to see if other subcontractor projects will affect flow of crews to this project. Team reviews plan for completing work in regards to plans, specifications and contract. This meeting includes attendance by subcontractors and their "sub-subs" to assure communication is delivered in full.

Formalized construction phase planning, execution, monitoring and feedback

- Subcontractor coordination meetings with recorded minutes. Each week the Quality Coordinator and Superintendent held a coordination meeting with all trades in the Job Trailer. All trades met to discuss their next steps in scope so that they can work together to find the most efficient way to work around each other based on the current 30 day schedule. This meeting was recorded with minutes and distributed to all attendees and the GCC management staff. Part of this meeting included a review of each subcontractor's two-week look ahead planning submittal. Individual meetings were held with each sub, each week to ensure the subcontractor was on schedule; had the manpower to maintain the schedule, and would have the materials on site to complete their scheduled work each succeeding week.

- Weekly submittals register updated. Since most construction products require technical approval from a designer before installation, this was a critical planning and monitoring process. This first component of material logistics, helped assure that a project will not be stopped due to lack of material.
- Progress schedule update. Each week, project manager reviewed the project schedule with the superintendent. Late progress is noted and addressed with deficient subcontractor(s).
- Weekly internal meetings. During this meeting, GCC reviewed the entire project status as a team. PM assigned weekly tasks if necessary. Everything was recorded and part of a later upper management review of project status.

Monitoring compliance to processes.

- The SVP actively measured compliance (as a percentage) to processes in face-to-face meetings and electronically (website and company intranet). He addressed non-compliance issues, as needed, with his staff and senior executives of subcontractors.

Limiting yearly contract revenue for various reasons including its focus on efficiency.

- They had less need to rehire former staff or hire new unproven staff because of this strategic decision. At times each year, estimators and business development personnel did not seek to win projects since company backlog was at a predetermined limit. For purposes of efficiency, when the firm won a project in an unfamiliar location, its first option was to send existing staff and not hire new local employees. Additionally, GCC essentially works with one client, the U.S. Government in repeating locations. This in turn means subcontracting to a significant percentage of familiar specialty contractors.

RECOMMENDATIONS

For the LC community, understanding the most efficient contractor's (GC and Subcontractor) methods of operating offers one way to improve construction's methods and processes. Interestingly, some of the practices shared in this paper align with the teachings of Lean while others do not.

From our case study, GCC's methods of extensive information gathering, engaged planning, measured compliance to processes, monitored schedule and when needed, executive level actions eliminating adverse planned to actual schedule gaps have positively transformed project results over a three year period.

This last method violates LC's instruction against command and control. However, most of the processes address decreasing the variability of inputs. Adhering to first principles appears to have efficacy in construction contracting. Based on the following recommendations, LC's outputs may improve even though causing more variability.

Planning

An extended and formalized pre-construction planning period is suggested. This process and its steps should be considered for LC to adopt in its library of practices. A formal period should be allocated where project teams are gathered to create many planning deliverables before construction may start. This requirement should be part of the bidding document's instruction and the project contract.

An extended pre-project planning period has many benefits such as normalizing the project team culture, setting expectations, and a deep familiarization of the project. Said differently, owners requiring extensive formal planning protect themselves and their projects against negative occurrences such as arbitrary change orders, unexamined risk events with no alternative planning, and unperfected communication systems.

On a highly organized construction project, acceptable planning deliverables could be compensated as pay item from each stakeholder's total contract amount. This would assure unanimous participation. The time period would be predetermined and articulated in the bid documents. When construction starts, all subcontractors should execute a short interval planning form and GC's should monitor for quality of thought including alternative plans.

Monitoring Compliance to Processes

It is widely believed that efficient processes executed consistently lead to the best outcome. Therefore, compliance measurement must be part of any improvement program. Employees consistently executing beneficial process give their project and company the best chance for positive result.

Measuring Schedule Results and Take Action

The last two components of PDCA, CA (Check and Act) are contained in this recommendation. Once results are measured, immediate action should be taken to replicate the superior result or correct the deficient outcome in concert with Subcontractor Senior Management.

Limited Revenue Business Model

All contractors aspiring to be Lean should commit to a targeted amount of contracted work annually that is a reasonable to their current capabilities. Part of this action should include attempting to work with familiar clients. Once the revenue goals and backlog are met, all company employees execute project work. This will help prevent high variability of client demand which leads to waste and in some cases, unfulfilled promises. To keep learning and constant improvement high, consistent employment of workforce members is needed. This influences each employee's learning and commitment to the company.

Large and often prestigious projects attract most contractors' attention. The effect of winning such work has to be analysed in regard to Lean principles including the impact on its long term philosophy and operational variability. Large resource demanding projects cause significant swings in several areas such as employee hiring and separation. Clearly, Lean instructs about being the best (most efficient), not the biggest or most prominent.

The seasonal and itinerant nature of construction is a barrier to a keeping a consistent employee population engaged. However, options exist for subcontractors to minimize this effect such as specialised winter work, excelling in a market niche or pre-fabrication of future work. At a minimum, keeping core employees working throughout the year has several benefits to a contractor on its Lean journey.

In all, monitoring of projected labour hours needed for each period (week or month) should be reviewed by executive management. Managing this actively should keep variability low and waste less than an ad hoc method. In the case of winning too much work, business development and estimating staff may have to be assigned to other duties such as field management or cost analysis for a period of time.

CONCLUDING REMARKS AND EXPECTED OUTCOMES

Familiar practices included in a new methodology increase confidence by construction professionals. At the same time, their efficient understanding in this unfamiliar methodology may be achieved. In some instances, LC may cloud contractors' understanding of LC processes or not inspire confidence with its unfamiliar vocabulary, processes and measurements. Further, it may be focusing on higher order behaviours when basic ones are more efficacious.

Some analysis of the most efficient contractors that may be practitioners of Lean or not, appears to be in order. This should help evolve LC into a more robust improvement methodology.

Currently, LC suffers from low adoption and the prospects in the future are poor. LC should consider adjusting its processes in the areas of information gathering, planning processes, process compliance and schedule adherence. If done, there is evidence that more successes may occur and LC's value would be easily recognizable by most construction firms. Shedding its manufacturing centric appearance and adopting familiar and proven practices of construction contracting should increase use by industry. LC possesses the framework, tools and practices that can transform the construction industry. However, its semi-rigid application of TPS to construction appears to not inspire contractor confidence.

Further research is needed to reformulate some methods of LC to address realities of GCs using subcontractors. Additionally, research of proven production methodologies executed by the most efficient construction contractors can help tailor LC closer to the needs of industry. Collecting more case studies examining processes coupled with quantitative results should help increase creditability and adoption.

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THE USE OF FIRST RUN STUDIES TO DEVELOP STANDARD WORK IN LIQUEFIED NATURAL GAS PLANT REFURBISHMENT

Vince Hackett [1], Christine Pasquire [2], Roy Stratton [3], Andrew Knight [4]

ABSTRACT

The refurbishment of existing Liquefied Natural Gas (LNG) plants is complex and potentially hazardous, so it is crucial that the workforce has the capability to undertake the work in an efficient and safe manner. One method to achieve this outcome is by the development of efficient work practices, fully utilising workforce experience and knowledge.

The purpose of this paper is to describe the outcomes resulting from the development and use of a lean tool referred to as Workshop First Run informed Work Design (WFRiWD) on the ongoing refurbishment of a Liquefied Natural Gas (LNG) plant in the North West region of Australia.

The paper identifies gaps in knowledge, where firstly there is little evidence of the use of a WFRS phase using existing resident knowledge to continuously develop and improve good practice. Secondly it addresses criticisms of the current issues the construction industry has in managing knowledge and thirdly it addressees the lack of literature and practice on the use of shared knowledge to enhance the development of high performance teams.

The tool has been developed and tested through Action Research cycles. The main result is the demonstration of how existing teams can evolve into higher performing teams using the WFRiWD tool in a collaborative knowledge sharing process.

KEYWORDS

First Run Studies, Work Design, Standardization, Deming wheel.

INTRODUCTION

This paper describes the use of planning workshops and first run studies to design and develop standard work for the refurbishment of LNG plants. The purpose of the planning workshops is for the engineers, superintendents, supervisors and leading hands to collaboratively conceptualise work designs which are then tested through site based First Run Studies (FRS) to develop improved standard work. This approach

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is one of a number of lean tools implemented on the refurbishment of the Karratha Gas Plant (KGP) in the Pilbara region of Western Australia.

The refurbishment is three years into an expected eight to thirteen year programme. The refurbishment works are being carried out under an Engineering, Procurement and, Construction Management (EPCM) form of contract. The facility itself is one of the largest integrated liquefied natural gas (LNG) plants in the world, contributing over 1% of GDP to the Australian economy. Working conditions are demanding with high summer temperatures experienced, rising to 45°C in the shade and above. Personnel operate for the most part on a fly in, fly out (FIFO) roster, usually on a two week on, two week off basis, operating in a back to back rotation system, where two people will rotate on the same job. This adds to the already complex work on live and offline process plant and makes for a challenging environment adversely impacting on productivity.

It is recognised that there are serious productivity deficiencies in the Australian oil and gas industry with an urgent need to better understand and then address the causes. Ellis, et al. (2013) report an escalation of costs over the last decade to a point where it can cost 20%-30% more to build in Australia than on comparable projects in North America. Lean tools have been implemented over a 17 month period to seek to address some of these productivity issues and engage the workforce in the sustainable embedment of a lean construction approach.

A literature search indicates a gap in knowledge where there is little academic or practitioner discussion on the use of a planning stage, allowing prototypes to be developed prior to testing on site in a FRS. Nguyen, et al. (2009) alone describes the use of a Virtual First Run Study (VFRS) as a distinct planning stage where prototypical solutions were developed for a viscous damping beam. In this instance the methods used were 4D simulation, integrated team coordinated meetings, process mapping and choosing by advantages (CBA). In the implementation described herein, integrated team workshops, process mapping and some 3D modelling are used in the planning stage. To differentiate the planning stage is referred to as Workshop First Run Studies (WFRS) with the combined tool called Workshop First Run Studies informed Work Design (WFRiWD).

WFRiWD combines planning workshops using resident knowledge to collaboratively develop prototypes, followed by FRS where the prototypes are tested on site. Prototyping is used extensively in many industries but has largely been ignored in the construction industry. The prototypes are standard work designs which Ballard (2014) says are “an explicit detailed plan for how a specific task will be done, developed collaboratively by those who will do the work”.

The WFRiWD tool utilizes the knowledge of the workforce. The importance of Knowledge Management (KM), involving the efficient flow of tacit and explicit knowledge within an organization has become increasingly important in the post-industrial era. There is a realization (Robinson, et al., 2005) of the need to be aware of the relative importance of tacit and explicit knowledge usage in the construction process with an understanding that tacit knowledge is of greater strategic importance than explicit in relation to business performance (Chen and Mohamed, 2010). Explicit knowledge can be codified but tacit knowledge (Polanyi, 1966) in a non-verbalized form of knowledge which is extremely hard if not impossible to codify. There is a fixation in construction on collecting “lessons learned” at the end of work, to codify all knowledge and develop “best practice” for use on future contracts (Carrillo, et al., 2013). However construction companies struggle to successful realize the potential of KM using this approach. The lessons experienced and “learned” are rarely successfully reintroduced (Paranagamage, et al., 2012), become lost in storage systems (Carrillo, et al., 2011) and IT is not capable of capturing tacit knowledge without losing its context (Malhotra, 2000).

Newell, et al. (2009), notes that “best practice” is a socio-political process of negotiation rather than an objective reality, the implementation of which leads to “vanilla” solutions, and that “skilled artisans will fiercely resist having their hard won tacit skills reduced and ‘fossilized’ in a process of codification” needed to develop “best practice” (Boisot, 1998: p 47). The outcomes from the current KM approach in the construction industry are underwhelming particularly with regard to effective knowledge transfer among and between teams.

Orlikowski (2006) refers to a “scaffolding of knowledgeability” which supports the transfer of knowledge between teams. The scaffolding denotes a broad class of physical, cognitive and social tools that allow teams to accomplish goals which would otherwise be beyond them (Clark, 2002). Nicolini, et al., (2012) describe tools or objects used in the transfer of knowledge and understanding in cross-disciplinary collaboration. These are referred to as boundary objects. This concept was developed within the field of science studies (Carlile, 2004; Levina, 2005) and boundary objects are described as being defined by their capacity to serve as bridges between intersecting social and cultural worlds. A range of objects can become boundary objects, including standardized forms, sketches and drawings (Carlile, 2002), physical objects, prototypes (Star and Greismer, 1989) and narratives (Bartel and Garud, 2003).

The paper discusses the development of high performance teams from existing ones when resident knowledge and experience is utilized in the WFRiWD process to continuously develop and embed good practice in the form of standard work. Chinowsky, et al. (2008) notes that high performance teams receive little attention in the construction industry. These teams exceed standard industry benchmarks by the development of an ability to continuously exchange knowledge and insights among the team. The paper reports on two different action research cycles where existing teams evolved into higher performing teams in the course of the implementation of the WFRiWD process. The WFRiWD tool was implemented alongside a number of lean tools, to directly address among other things, shortfalls in current construction KM practice. These teams consisted mainly of supervisors and leading hands using the tool collaboratively, sharing knowledge and insights to develop continuously improved standard work.

The aim of this paper is to report on the implementation of the WFRiWD process and in so doing address the gaps in the literature which includes the paucity of research in the use of planning workshops in the development of standard work design, the issues construction organisations experience in the successful use of KM and the lack of discussion directing the evolution of high performance teams in construction environments.

The outcomes showed how the teams implemented the tool often requiring a low level of researcher (lead author) input, displaying an innate awareness of Deming wheel concepts despite having no previous formal exposure to the concepts.

WORKSHOPS AND IMPLEMENTATION

The implementation of the WFRiWD used the guidance of Ballard and Howell (1997: pages 125-126) who say that the planning and implementation exercise should be carried out as follows in order to develop standard work packages:

Plan

1. Select the work processes to study.
2. Gather the people for the planning phase who can provide input and impact.
3. Collaborate using past experience to develop good practice.
4. Anticipate hazards and specify preventions.
5. Assign optimum labour, tool and equipment resources.

Do

6. Try out the prototyped work in the FRS phase.

Check

7. Describe and measure what actually happened, process steps, durations, errors, omissions and reworks, near misses and hazards, resources used and outputs.

Act

8. Reconvene the team, especially those involved in carrying out the work. Review data and share experiences. Continue to refine the standardised work.
9. Communicate the improved standardised approach to the workforce.

Ballard and Howell (1997, p. 215) note that "the intent is to thoroughly plan and study first run studies of operations, using past studies as guidelines and producing standard work method designs for use on the project. This experiment – based approach produces a tested method that can be taught to all crews, thus reducing cost, errors and accidents... once workers see that you are interested in finding better ways of doing work, they will develop and share their ideas".

METHODS

The research used an action research (AR) approach. Action research uses action – reflection cycles in a process of observe-reflect-act –evaluate- modify – move in a new direction. Coughlan et al note that action research uses

"A scientific approach to study the resolution of important or organizational issues together with those who experience these issues directly. The goal is to make that action more effective while simultaneously building up a body of scientific knowledge" (2009: p. 5).

During the course of the primary research, action research was used to implement change by the use of lean tools including the LPS and WFRiWD. The AR process included organizing the required meetings and workshops and then facilitating and mentoring people during the course of the implementation. The AR was cyclical and iterative in nature with the outcomes from one cycle informing the development of the plan in the following cycle. The AR cycles were implemented over a 17 month time period.

DEVELOPMENT OF THE BOUNDARY OBJECTS

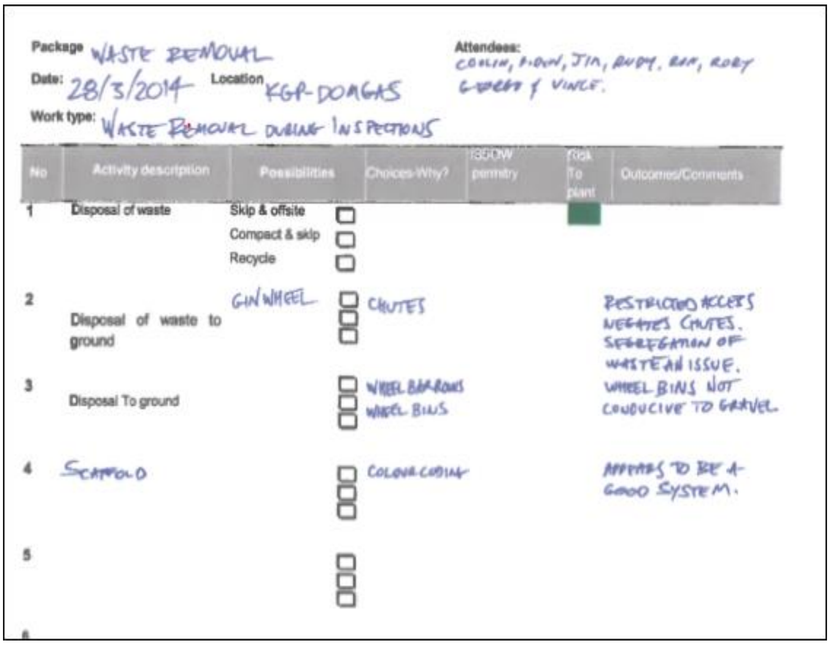
Much of the early implementation work involved the identification of the most appropriate boundary objects. As discussed above boundary objects may be artefacts or narratives that aid transfer of knowledge and the formation of common understanding (Pasquire, 2012) between interrelated teams.

The WFRiWD tool was implemented alongside the Last Planner® System (LPS). Whilst the use of the LPS has been well documented and understood over the last two decades there is little literature on the implementation of FRS informed by a stand-alone planning phase as a part of the iterative Deming Wheel cycles.

A number of workshops involving engineers, superintendents and supervisors were undertaken to identify the most suitable boundary objects to most efficiently transfer knowledge in the development of standard work design. The first workshop explored the use of a pro-forma (figure 1), to develop standard work design for inspection work scopes. The workshop demonstrated that the pro-forma had some drawbacks in that it limited the collaborative potential of the teams.

Following analysis of the outcomes of the first workshop, a revised boundary object was used in subsequent workshops where whiteboards and post-its were used. This facilitated discussion between the participants, so identifying good practice and potential improvements for example in inspections undertaken from rope access and scaffolding.

The workshop consisted of the visual tracking of the work involved in inspection from ropes and scaffoldings. The main takeaway from these workshops was that good practice was identified, the workforces were willing to engage in the workshops and that the most suitable boundary object was the white board (Figure 2).


Package: WASTE REMOVAL
Date: 28/3/2014 Location: KGP-DOMGAS
Attendees: [illegible]
Work type: WASTE REMOVAL DURING INSPECTIONS

No	Activity description	Possibilities	Choices-Why?	ISSOW permitry	Risk To plant	Outcomes/Comments
1	Disposal of waste	Skip & offsite Compact & skip Recycle				
2	Disposal of waste to ground	GIN WHEEL	CHUTES			RESTRICTED ACCESS NEGATES CHUTES. SEGREGATION OF WASTE AN ISSUE.
3	Disposal To ground		WHEEL BARROWS WHEEL BINS			WHEEL BINS NOT CONDUCIVE TO GRAVEL.
4	SCAFFOLD		COLOUR CODING			APPEARS TO BE A GOOD SYSTEM.
5						

Figure 1. WFRS pro-forma

The boundary object used during the course of the workshops to transfer tacit knowledge was the use of narratives. Another boundary object used was the interactions and discussions of the interrelated teams as they worked together on the work fronts.

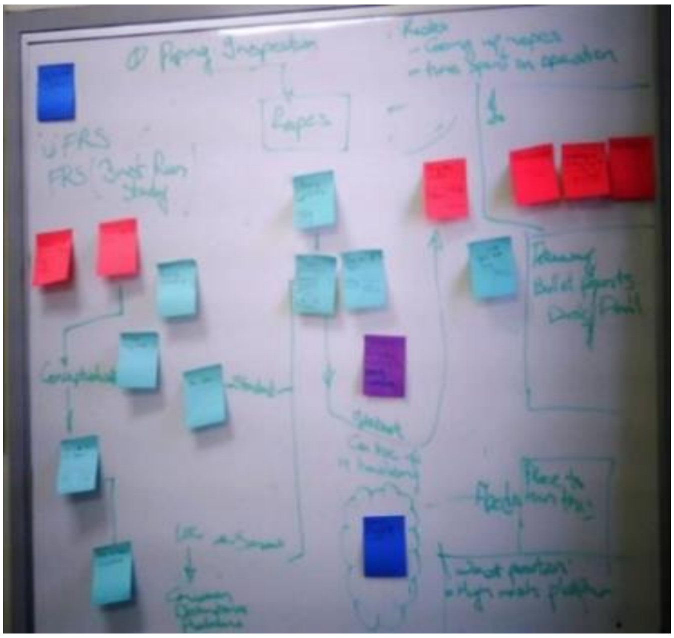


Figure 2. White board with post –its

ACTION RESEARCH: IMPLEMENTATION OF WFRIWD

In order to ensure the sustainable development of the high performance teams, the development and use of the WFRiWD tools was led by teams, aided by some researcher facilitation in the following situations:

- Workshops informed by questionnaires
- Continuous Improvement cycles by the workforce

Workshops informed by Questionnaires

This approach was used by the inspectors involved in diagnosing and developing the ongoing plant refurbishment scope of work. The inspectors work in small teams and display a unique array of skills. The inspections are undertaken mostly from rope access. The nature and complexity of the inspections and reporting demands a high degree of physical and mental dexterity. As a result inspection teams comprise people who are physically and mentally resilient, who will only engage with change when it is seen to have potential value. The WFRiWD was accepted as a tool that would provide improved outcomes.

The boundary object first employed was a white board with post-it's using a pull-planning format. The outcomes were implemented on site and refined using the PDCA cycle.

Ongoing discussions with the inspectors supported the hypothesis that a high level of tacit and explicit knowledge resides in the workforce consciousness. This provided a rich source of knowledge informing the workshops. The lead inspection engineer, an early lean construction adopter developed a questionnaire to tap into the workforce experience and knowledge. The feedback from the questionnaires, (example Figure 3), provided rich information informing the WFRS phase. There were 11 areas addressed with "key takeaways" developed for further work-shopping.

EPCM Key Takeaway:

The integration of the Last Planner System has provided the implementation contractor with the opportunity to own the schedule.

The sporadic and late delivery of work- packs hindered the ability to correct plan and manage the scope.

Changes in priorities affect productivity, having to mobilize personnel to different areas of the plant to meet imminent deadlines is best avoided through sufficient planning.

Figure 3. Questionnaire Key Takeaway

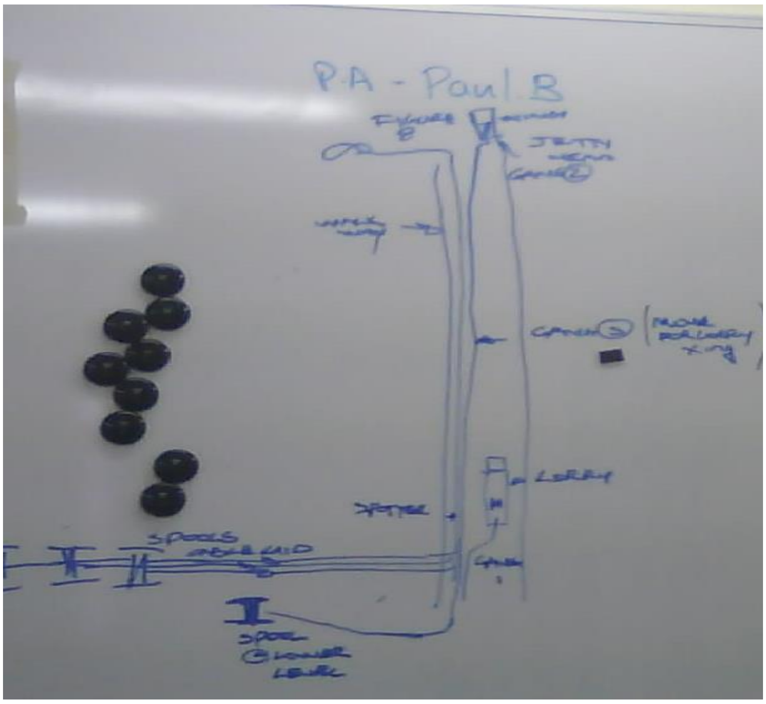


Figure 4. WFRS on white board

This approach addresses criticisms of current organizational knowledge management (KM) discussed previously. Here KM is contemporaneous, using the workforce knowledge and engagement to develop continuously improving standard work.

WFRiWD led by the Workforce

The WFRiWD lean tool was implemented along with the LPS by the workforce on jetty refurbishment scope. The jetty is a key installation used to load product to ships for export to market. In this instance the workforce was already using the LPS and also used a WFRiWD type tool.

The work scope was complex, including civil, electrical and mechanical scope with inherent hazards and restrictions due to the ongoing loading of ships with hydrocarbon product. These constraints meant that the workforce had to continuously develop and improve the work design to maintain efficient workflow.

A particular work scope was the installation of power and instrumentation cabling. The conceptualized work design was initially developed by the supervision using a white board (figure 4). The outcome from this workshop was implemented on site in a FRS (figure 5).

Figure 5. Use of winch

Figure 6 . Use of Lorry

The initial FRS and subsequent iterations of the WFRiWD identified improvements, which included the use of a wagon to assist in the cable laying operation (figure 6). This was deceptively complex work and the methodology was refined through ongoing iterations of the WFRiWD. In this way the workforce was able to improve production considerable and also improve safety and quality outcomes. The work groups continued to use this approach to develop and optimize standard work for the ongoing jetty scope of work.

It is significant that the contractor's construction supervisor could describe the methodology he used. He described the philosophy and process as follows: Firstly he (MP, the implementation contractor's supervisor) walks the course with his leading hands (LHs) and they talk through how they are going to do the work. He will suggest a method to get the discussion going, they may come up with a different approach, and by doing this he is getting a buy in from the LH's. For instance on pulling the cables from the drums. MP wanted to leave the cables on the drums and go through the stairs, the LH's proposed an alternate route and method. The alternative solution was used and worked well.

The supervisors and LH's normally use the white board (figure 4) to draw up and get a visual on the work flow. The LH's then draw up the SWMS (safe work method statement) which is a simple bullet point description of the work. These are the outcomes from this approach as described by the supervisors involved:

- The LHs create the philosophy and develop the work design.
- The workforce know the job because they own it and built it.
- People sometimes struggle with complex drawings but understand the job from discussions and the visuals.
- The process gives a common sense of ownership to those involved.
- Relationships are strengthened as team members are tutored, coached and mentored in the walkthrough and team members build broader relationships with each other.

- Crew members understand each other's individual strengths and weaknesses as a result of the rich conversations that occur.
- Problems that are difficult to resolve are left by team consent with the commitment to come back later with a fresh perspective.
- The process delegates the work to the LH's and confirms the LH's understanding of both the scope and hazards.
- People discuss the productivity rates they will expect and take ownership of both process and what success looks like.

CONCLUSIONS

The study addressed the introduction and use of a tool described as WFRiWD. This tool uses a distinct WFRS phase in a Deming wheel cycle (PDCA) to develop work design that can then be tested by the workforce in on site FRS. By using ongoing iterations of the Deming wheel continuously improved standard work was developed.

The research addressed a number of gaps in knowledge. The first is that whilst FRS is a tool used in lean construction, when used it is normally there is no evidence of the use of a distinct planning phase. The gap was addressed by the development and use of a WFRiWD tools that employs a WFRS to develop conceptualized work design before introduction on site in a FRS to develop continuously improved standard work approaches. The WFRS workshop collaboratively draws in decision makers, using their tacit and explicit knowledge to build the conceptualized work designs. In this way knowledge and experience is being utilized to develop continuously improving good practice suitable to a particular environment, in this case the Karratha Gas Plant. The second gap is the lack of literature describing a successful use of KM in construction. This gap was addressed by the use of the WFRiWD process engaging the workforce to use their knowledge in the contemporaneous and continuous development of standard work at the work fronts. This third gap is the lack of literature on the development of high performance teams in construction, which was addressed by the development of higher performing teams using the WFRiWD tool as a mechanism to transfer knowledge among and between teams.

The research and implementation resulted in a number of outcomes which included the development of a formal process to use the WFRiWD tool. It also demonstrated the capabilities of the workforce to intuitively grasp the concepts of the Deming wheel and prove ability to lead the development of standard work. Other outcomes included the development of a site-based initiative using a workforce questionnaire to provide input for the workshops. The implementation also demonstrates the potential for the successful implementation of the tool particularly when supported by workforce engagement. All this aided the ongoing development of high performing teams. Higher performance was demonstrated by the ability to continually learn, improve workflow and achieve improving productivity levels above the site norms.

The limitations of the research is that to date the implementation has been carried out only on the refurbishment of LNG plant. There is a need to undertake further research on other types of construction to assess the outcomes from implementation of the WFRiWD tool.

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INTERPLAY OF LEAN THINKING AND SOCIAL DYNAMICS IN CONSTRUCTION

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ABSTRACT

Production, commercial, technical, organizational and social aspects must be managed simultaneously for a construction project to be successfully delivered. However, most management approaches in construction are technically-oriented methodologies that largely neglect central social aspects related to people's behaviour. Lean construction research has likewise focused more on technical and commercial aspects than on social aspects. Recent research in the domain has aroused interest in various social aspects, such as the language-action-perspective, people development, culture and transformation, and integral theory. Yet little research has been pursued to understand the interactions between lean construction thinking and the social dynamics within construction project organizations. To begin to bridge this gap, the latent synergy and feedback loops between lean construction practices and social dynamics variables such as trust, goal setting and power distance in construction are discussed in this paper. The interplay between lean construction tools and the social dynamics variables is illustrated through an example based on the Last Planner System (LPS). We argue that lean tools work better when the environment is less autocratic, the team is more integrated, and the levels of trust between project team members are higher. In this organizational environment power-distance is decreased. Lean and goal setting also seem to interact positively and motivate the team.

KEYWORDS

Goal Setting, Last Planner System, Power Distance, Social Dynamics, Trust.

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INTRODUCTION

Projects in construction take place under dynamic and unsteady site conditions, with considerable levels of uncertainty. They are conducted by temporary organizations and executed in provisional production facilities (Koskela, 2000; González and Alarcón, 2010). Two different, but symbiotic aspects emerge from this characterization. Construction can be understood as: (i) a production process (Koskela, 2000), and (ii) a social process (Hill, 1995). Thus, both production and social aspects should be managed simultaneously for a project to be successfully delivered. However, 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). Disputes and conflicts (Cheung and Yiu, 2006), industry fragmentation, highly hierarchical organizations (Emmitt and Gorse, 2009), and lack of communication and trust (Palacios, Gonzalez and Alarcón, 2013), among others, are symptoms that construction does not account much for its social issues, which in turn negatively affect its production performance.

On the other hand, a shift towards people-based managerial approaches has been widely acknowledged by new management philosophies and every type of innovation involving changes in organizational practices (Kofman, 2008). Lean thinking has been an influential force to shape modern manufacturing organizations towards value and people-centred organizations (Womack and Jones, 1996). As a management philosophy, lean thinking has proved capable of improving the performance of firms and organizations, via a suitable implementation of tools and processes (Womack and Jones, 1996). In order to achieve excellent results, lean organizations require not only effective implementation of business purposes and processes, but also teams led by responsible people to carry them out (Womack, 2006). Lean thinking pays much attention to the social mechanisms of organizations, which help develop and empower people, promoting understanding of people's motivations (Liker, 2004).

Lean thinking has been applied systematically to construction over 20 years (Alarcón et al., 2005), 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 issues, such as the language-action perspective (Macomber and Howell, 2003), people development (Pavez and Alarcón, 2007), culture and transformation (Alarcón et al., 2006), and integral theory (Pavez, González and Alarcón, 2010), little research has been undertaken to understand the interactions between lean thinking and the social behaviour in a construction organization. A better understanding of the interplay between lean thinking and social dynamics in construction is needed.

Social dynamics refers to the resulting behaviour of groups from the interactions of its individual members and the analysis of the connections between individual interactions and group level behaviours. Social dynamics assumes that individuals are influenced by one another's behaviour and is concerned with changes over time emphasizing the role of feedbacks (Durlauf and Young, 2001). A better understanding on how lean thinking and social dynamics interact within construction organizations is required to identify what are the most influential social drivers to support smooth implementation of lean thinking. In turn, more effective strategies can be designed to help construction organizations to become lean organizations.

The goal of this work was to explore the latent synergy and feedback loops between lean thinking and social dynamics variables such as trust, goal setting and power distance in construction. To do so, we theoretically characterize the relationship between different organizational, decision-making and management structures, and social dynamics. An example with the Last Planner System (LPS) was modelled to illustrate the theoretical interplay between lean tools in construction and the social dynamics variables. The next sections will discuss the social dynamics variables studied, the characterization of social dynamics in traditional and lean organizations, and the conceptual modelling framework using the LPS example.

SOCIAL DYNAMICS VARIABLES

Numerous social dynamic variables of construction organization are affected when lean tools are used (Pavez and González, 2012). We focus on three specific social dynamics variables: trust, goal setting and power distance.

People depend on others in various ways to accomplish their personal and organizational goals. There is an inherent risk that could be reduced if people trusted each other. Based on the relationship between risk and trust, Mayer, Davis and Schoorman (1995) proposed one of the most used operational definitions of trust in management research: *"the willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party"* (p. 712). In general, a trustor will be willing to be vulnerable to another party based both on the trustor's propensity to trust other people in general, and on the trustor's perception that the particular trustee is trustworthy. In this regard, Mayer, Davis and Schoorman (1995) posed that: trustworthiness is comprised by three factors: ability, benevolence, and integrity.

The goal setting theory is one of the most widely used motivational theories. There is an underlying assumption that as behaviour reflects conscious goals and intentions, employees' efforts and performance in organizations will be influenced by the goals assigned to, or selected by, these employees. Therefore, goal setting theory states that the performance of a team will be high if the related goals are difficult, specific and attainable (Steel and König, 2006).

Power distance refers to how power is distributed in organizations and how people pertaining to a specific culture perceive power relationships (superior – subordinate). It also can be understood as an opposite force to trust and defined as the degree of centralization of authority and autocratic leadership (Hofstede et al., 1990). People belonging to high power distance cultures easily accept that power is distributed unequally and believe that the relationship between superior – subordinate is one of dependence. In contrast, people in low power distance cultures question authority, expect at least some level of participation in decisions, and perceive the relationship between superior – subordinate as one of interdependence (Hofstede et al., 1990).

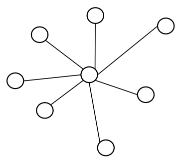
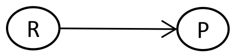
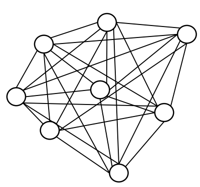
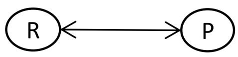
THEORETICAL CHARACTERIZATION OF SOCIAL DYNAMICS IN TRADITIONAL AND LEAN CONSTRUCTION ORGANIZATIONS

It is argued that the structural features of an organization can shape its social dynamics and vice versa. Therefore, a theoretical characterization of this relationship can shed light about what these factors are and how they help to enhance the social performance of construction organizations. In this section, the relationship between different aspects of traditional and lean construction organizations and social dynamics is theoretically characterized using their typical project delivery system, decision-making structure, action workflow and operating system, which are in turn related to the social dynamics variables.

RELATIONSHIP AMONG PROJECT DELIVERY, ORGANIZATIONAL STRUCTURE AND OPERATING SYSTEMS

In Table 1, project delivery system, organizational structure and operating system are characterized for both traditional and lean construction organizations.

Table 1: Project Delivery, Organization Structure, and Operating System Characterization.

Project Delivery System	**Decision-Making Structure**	**Action Workflow**	**Operating System**
	Traditional Construction Organization		
Silos of responsibility that prevents capability to collaborate (Smith and Rybkowski, 2012). Centralized decision-making, command and control (Alarcón, Harrison and Howell, 2013). Motivating approach: Pressure participants along the critical path to complete work timely and under budget (Alarcón, Harrison and Howell, 2013) and communicate urgency to motivate them to take action (Macomber and Howell, 2003).	 *Centralized* (Malone, 2003)	 R requests the completion of a task "x" to P. Hence, P promises the completion of x. Roles R and P are fixed as conversations become essentially directives between R and P. Thus, coordination and negotiations capabilities between agents (R and P) are very limited (Macomber and Howell, 2003; Lichtig, 2006).	*Activity-centered/* Critical Path Method (CPM) (Alarcón, Harrison and Howell, 2013)
	Lean Construction Organization		
High levels of organizational integration and collaboration. Highly shared decision-making (Alarcón, Harrison and Howell, 2013) and decisions by consensus (Lichtig, 2006) Motivating approach: LPD builds on trust and collaboration (Alarcón, Harrison and Howell, 2013).	 *Decentralized-Networked* (Malone, 2003)	 R requests the completion of a task "x" to P or vice versa. Coordination and negotiations usually take place in a highly collaborative environment, in which conversations between R and P represent the basis for the action. Also, roles can be interchangeable, i.e sometimes R can be P and vice versa (Ballard, 2000; Macomber and Howell, 2003; Lichtig, 2006).	*Flow-centered/* Last Planner System (LPS) (Alarcón, Harrison and Howell, 2013)

The development of construction projects typically embraces three fundamental areas: commercial terms, organizations and an operating system, which are shaped by the cultural and technological attributes of the organization (Thomsen et al., 2009).

Commercial terms are usually characterized by a project delivery system (PDS) (Alarcón, Harrison and Howell, 2013), which represents how participants or "agents" interact at organizational level, converting owner's goals into finished buildings (Chen et al., 2011). The most common traditional project delivery systems (PDS) are Design-Bid-Build (DBB), Design-Build (DB) and Construction Management at Risk (CMR) (Konchar and Sanvido, 1998; Alarcón, Harrison and Howell, 2013). In contrast, Integrated Project Delivery and Lean Project Delivery (LPD) have emerged as alternatives to traditional PDS (Lichtig, 2006). LPD in particular is based on lean thinking principles and tools, early involvement of parties and a collaborative work environment (Lichtig, 2006). In Table 1, the traditional and lean cases are illustrated by DBB and LPD respectively.

Construction organizations are also characterized by their decision-making structure and their action workflow (Table 1). The decision-making structure describes how decisions and communications are distributed within an organization (Malone, 2003). In this regard, organizations can be characterized as independent-decentralized (agents have low needs for communication and interaction as they make decisions independently and are not necessarily connected), centralized (agents have significantly higher communication and interaction needs to make decisions, they are connected to one or few "key" decision-makers, and there is command and control), and decentralized-networked (agents generally require even more communication to make decision than centralized ones, they are fully connected to one another, and they tend to collaborate) (Malone, 2003). Action workflow is an approach based on the language-action perspective (LAP) that helps to understand how agents are coordinated through language in an organization and define what exactly flows between them. Action workflow focuses not on tasks but on the speech acts that constitute these tasks (Kethers and Schoop, 2000). Thus, an organization can be described as a network of commitments (promises) between requestors (R) and performers (P) which also represent the parties or agents of an organization (Macomber and Howell, 2003). The operating system shown in Table 1 can be understood as the way work is managed in a project (Howell, 2010). The traditional operating system is activity-centred, in which the project plan is seen as a network of tasks executed by trades. The main goal is to optimize the project by optimizing the pieces, i.e. each activity (Howell, 2010). The Critical Path Method (CPM) is typically used to plan and control the work under this operating system (Alarcón, Harrison and Howell, 2013). In the lean operating system, a flow-based strategy is used in which predictable and fast-paced workflow is typically achieved through a project conceived as a production system. The main goal is to optimize the project, not the pieces, by making workflow predictable (Howell, 2010). The Last Planner System (LPS), a popular lean production planning and control system, is used by this operating system (Alarcón, Harrison and Howell, 2013).

SOCIAL DYNAMICS IN TRADITIONAL AND LEAN ORGANIZATIONS IN CONSTRUCTION

Table 2 shows the relationship between traditional and lean organizations in construction and the different social dynamics variables studied. As suggested in Table 1, a traditional construction organization can have a DBB as PDS, a centralized decision-making structure, an action workflow between R and P agents represented by directives, and an activity-centred operating system. A traditional PDS does not necessarily encourage communication and collaboration between the project parties as it defines a contractual and relational framework that is adversarial in nature (Alarcón, Harrison and Howell, 2013; Palacios, Gonzalez and Alarcón, 2013). Conversations within the organization are reduced to requests and directives from R to P. Also, commitments between them are not built up on a reliable basis as an appropriate coordination and negotiation process does not take place (Priven and Sacks, 2015a). In addition, traditional construction organizations commonly have a business environment plagued with claims and litigation (Cheung and Yiu, 2006), which is an indication of a low degree of organizational trust as shown in Table 2. In this type of organization, the centralized authority and decision-making structure along with a low degree of organizational trust suggest unequally distributed power (Priven and Sacks, 2015a), which implies a high degree of power distance. Under a traditional PDS, construction organizations are usually highly disintegrated, hence work related to the development of a project is difficult to coordinate due to existing organizational silos (Alarcón, Harrison and Howell, 2013; Palacios, Gonzalez and Alarcón, 2013). Also, the way in which the operating system works is not very efficient as the trade work typically is planned and controlled using CPM tools (Alarcón, Harrison and Howell, 2013). Thus, they are unable to effectively coordinate different trades and provide clear directives to them of what can be done on-site (Ballard, 2000). Table 2 suggests that the goal setting degree is low as production goals are not very specific, clear or challenging for trades.

Table 2: Characterization of Social Dynamics Variables in Traditional and Lean Construction Organizations

	Trust Degree	**Power Distance Degree**	**Goal Setting Degree**
Traditional	Low Adversarial relationships. Limited collaboration and communication. Unreliable commitments (Smith and Rybkowski, 2012; Alarcón, Harrison and Howell, 2013; Palacios, Gonzalez and Alarcón, 2013; Priven and Sacks, 2015a).	High Unequally distributed power and centralized authority (Pavez and González, 2012; Alarcón, Harrison and Howell, 2013; Palacios, Gonzalez and Alarcón, 2013; Priven and Sacks, 2015a).	Low Less clear and/or challenging goals (Pavez and González, 2012).
Lean	*High* Highly collaborative and integrated relationships. Enhanced communication Reliable commitments (Smith and Rybkowski, 2012; Alarcón, Harrison and Howell, 2013; Palacios, Gonzalez and Alarcón, 2013; Priven and Sacks, 2015a).	*Low* More evenly distributed power and descentralized-networked organization (Pavez and González, 2012; Alarcón, Harrison and Howell, 2013; Priven and Sacks, 2015a).	*High* Specific and clearly defined goals. More challenging, but achievable goals (Pavez and González, 2012).

The lean construction organization defined in Table 1 has the LPD as PDS, a decentralized-networked decision making structure, an action workflow between R and P agents represented by two-sided conversations and reliable commitments and a flow-centred operating system. A lean PDS tends to integrate more tightly the different parties of a project, where trust and collaboration are the basis of their relationships (Alarcón, Harrison and Howell, 2013; Palacios, Gonzalez and Alarcón, 2013). Conversations between R and P are made in a highly collaborative environment that engenders reliable commitments as an appropriate coordination and negotiation process take place (Priven and Sacks, 2015a). Accordingly, Table 2 shows that the degree of organizational trust is high. Decentralized-networked decision-making structures and higher degrees of trust have been observed in lean organizations, which suggests a low degree of power distance (Priven and Sacks, 2015a). In addition, LPS has proven to be an efficient operating system to plan and control trade work in construction organizations willing to become lean organizations (Alarcón, Harrison and Howell, 2013). LPS is able to control the workflow between trades and provide a reliable and clear basis to define what can be done on-site (Ballard, 2000). Thus, Table 2 proposes that the goal setting degree is high as production goals are specific, clear and challenging for trades.

CONCEPTUAL MODELING FRAMEWORK OF SOCIAL DYNAMICS WHEN IMPLEMENTING LEAN TOOLS

In this section, the conceptual modelling framework of the interplay between social dynamics and lean thinking in construction is illustrated using an example with the LPS. The synergy and feedback loops between LPS and social dynamics are theoretically modelled. In Table 1, LPS falls into the “pure” lean category. However, a traditional organization in the process of becoming lean may have some of the lean elements shown in Table 1. For instance, a traditional/lean organization may have a DBB contract as PDS, LPS as operating system, and a partially decentralized organization.

Pavez and González (2012) have discussed how theoretically LPS and the social dynamics variables (trust, goal setting and power distance) could interact. Figure 1 shows a conceptual model of the hypothetical relationship between LPS and the social dynamics variables studied, and the resulting feedback loops and synergies. Note that only some LPS components and aspects have been used in the illustration. Pavez and González (2012) claimed that one of the deepest changes in successful projects using the LPS is the decrease of power distance. LPS helps to lift trust within the project, because the dynamic of the weekly work plan meetings decreases the perceived autocratic leadership and promotes positive exchanges between team members as the manager begins to listen more. This effect has been observed in four projects in which the 'Social Subcontract' was implemented together with the LPS (Priven and Sacks, in press). When this happens, PPC increases and the manager’s behaviour during the meeting turns from advocacy to inquiry. Mayer, Davis and Schoorman (1995) stated that the variation of the attribution on trustworthiness varies the perceived level of trust between parties. Accordingly, incidents or actions that prompt a reappraisal of any of the trustee perceptions will impact trustworthiness and hence the perceived level of trust. Pavez and González (2012) argued that this social mechanism takes place within the LPS as the teamwork dynamic allows the perceived ability of the project team to be enhanced.

As a result, the LPS implementation may increase the perceived level of trust among project agents by enhancing their perceptions of their partners’ ability, integrity and benevolence. Thus, LPS helps to reduce power distance, by allowing the agents of the project team to pool their own viewpoints with those of the manager in such a way that the comments made by the manager are no longer perceived as orders, but as a way to understand other's perspectives with the aim of improving project performance (Pavez and González, 2012). As power distance decreases, communication channels are opened and collaboration is encouraged. Thus, the degree of trust shifts from low (traditional) to high (lean) within the organization.

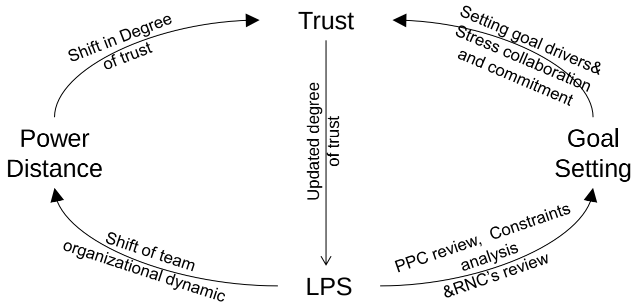


Figure 1: Feedback loops and synergy between LPS and social dynamics variables.

LPS allows the project team to set specific, challenging and achievable goals. Ballard (2000) proposed the definition of these goals through the quality criteria for assignments that are part of the weekly work plan: definition, soundness, sequence, size and learning. In this regard, the constraints analysis process is instrumental, as what will be done is assessed against what can be done. The reliability of the commitment plan is tracked using the percentage of plan completed (PPC). Pavez and González (2012) claimed that PPC was originally created to manage the workflow uncertainty from a purely technical standpoint; however, PPC works as a social agreement that changes team dynamics as well. In particular, they argued that the process to build up the commitment plan and the systematic PPC review increase the commitment and alignment with the team goals (project performance). Pavez and González (2012) pointed out that the PPC evolution (when improved) linked with the Reasons for Non-Completion (RNC) allows the team to assess the perception of the past experience in a positive way, which guides the selection of more challenging and attainable future goals. Thus, the LPS implementation may improve goal-setting for planning project tasks (difficult, specific and attainable).

As mentioned, LPS changes power distance, which in turn influences the level of organizational trust through changes in the organizational dynamics. On the other hand, LPS modifies the organizational goal setting by acting on the PPC review, constraints analysis process and RNC review. The power distance-goal setting interaction allows the levels of trust to be updated and improved, which impacts on LPS, in turn engendering synergies and feedback loops with the social dynamics variables.

CONCLUSIONS

This research has discussed the interplay between lean thinking and social dynamics in construction, through the analysis of a conceptual model representing the implementation of the LPS. From a practical standpoint, the model and the discussion provide guidelines for considering which social aspects are critical in the implementation of lean construction tools and what are the potential impacts and opportunities at both organizational and production levels.

The synergies and feedback loops between LPS and the social dynamics variables are modelled simplistically and several assumptions have been accepted to do so. A more comprehensive characterization of feedback loops and synergies between the studied variables is being developed and a numerical simulation is being prepared to enable research of the phenomena.

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ANALYZING THE INTERRELATION BETWEEN MANAGEMENT PRACTICES, ORGANIZATIONAL CHARACTERISTICS AND PERFORMANCE INDICATORS FOR CONSTRUCTION COMPANIES

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ABSTRACT

Recent studies have established the importance of best management practices in company performance measured by productivity, safety and other performance indicators. Research about the relationship between the characteristics of the organization and its performance has not yet arrived to definitive conclusions. This research aims to examine the relationship between management practices, characteristics of organizations and the project performance. Knowing these relations is necessary to achieve better management strategies. This paper presents results of the first application of a benchmarking effort carried out among nine Chilean construction companies. Management practices, grouped in fifteen dimensions, were assessed from data obtained through surveys. Weighted average of the responses from each survey was used to obtain scores for each dimension. Social Network Analysis (SNA) was used to capture characteristics of the organization on relevant issues such as communication; planning and personal issues and its metrics were the input for the analysis performed. Project performance was measured using nine key performance indicators (KPI) that were periodically reported by the companies. Correlation analysis was used to analyse the relationship among management practices scores, social network metrics and KPIs. The results show significant relationships that can be useful to design performance improvement strategies for companies and projects.

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KEYWORDS

Lean construction, flow, network, complex, SNA.

INTRODUCTION

Construction industry has been defined as a complex and apparently unpredictable business (Esa, et al., 2014). Because construction enterprises are project oriented its success depends on the projects performance. Some internal and external factors have been proposed as determinant of project performance but there is still not agreement on the main variables. Among the inside factors, management practices and human related issues are commonly cited such as (Chan, et al., 2004; Orozco, Serpell, and Molenaar, 2011).

In this way, recent studies have established the importance of management practices in the performance of enterprises (Bloom, et al., 2011) and construction projects (Ramirez, Alarcón, and Knights, 2004; AlSehaimi, et al., 2014). Therefore, it has been emphasized the need to understand how human related organizational issues influence projects performance since informal organization traces the routes by which information flows inside the companies (Flores, et al., 2014). From Lean construction (LC) perspective, the flow of information affects all other resource flows (Koskela, 2000) (Dave, et al., 2014). Thus, effective management, with a constant flow of information is necessary for Lean production operations.

The purpose of this study is to reveal the relationship between organization characteristics, management practices and performance in construction projects. Knowing the relationships is a useful piece of information to implement strategies for enhancing project performance.

METHODOLOGY

SAMPLE

The present study was performed during one year in 9 construction companies operating in Chile. Project performance was evaluated in 41 construction projects, ranging from 5 to100 million USD that include housing, buildings and industrial assembly. A total of 712 people participated in surveys of management practices. Also 410 employees were surveyed to determine social network characteristics.

LITERATURE REVIEW

Literature review was carried out in three different fields: construction performance measurement, management practices and corporative social networks. The purpose of the literature review was to identify the most commonly used indicators or metrics and methodologies for data collection.

Key Performance Indicators are measures used to monitor, control project performance and conduct benchmarking. There seems to be a common listing of KPIs for construction companies regardless of the project management perspective (Radujković, Vukomanović, and Dunović, 2010) including both leading or process indicators and lagging or outcomes indicators (Yeung, et al., 2013; Costa, et al., 2014; Nassar and Abou Rizk, 2014).

A management practice is a process or method that is usually applied in the management of a company. With the aim of developing a list of management practices, we did a literature search on the most common dimensions (groups of practices) used in management evaluation. (Bassioni, et al., 2004; Ramirez, Alarcón, and Knights, 2004; Jin, et al., 2013; Kim, 2014)

It has been suggested that social networks portray the organization better than charts (Krackhardt and Hanson, 1993). Most common social network metrics and their meaning associated to graph theory were taken from recent bibliography (Easley and Kleinberg, 2010). Social Network Analysis (SNA) techniques and software references are becoming friendlier and frequently used (Abraham, et al., 2009). In construction industry particular uses of SNA have started to be published recently (Alarcón, et al., 2013; Priven and Sacks, 2013).

SOCIAL NETWORK SURVEY

Social network data were gathered by the Center for Excellence in Production Management – GEPUC. A survey was designed and conducted about the interaction between people working in the construction companies. The questionnaire has six questions to explore communication for: Innovation development, personal confidence, planning and problem solving, relevant information exchange and personal issues. The frequency of the interaction was investigated too.

Through an online survey each member had to report who he/she exchanges information with, instead of relying on the available information such as email exchange. This approach allows the identification of the expected formally identified interactions and the informal interactions that develop during the labor time.

MANAGEMENT PRACTICES SURVEY

To define important management practices four workshops were conducted with managers of participating companies. The selected management practices were grouped into 15 dimensions: quality, communication and information, costs and schedule, suppliers, risk, innovation, leadership, corporate goals, organization and change, planning and programming, production, human resources and corporative learning, labor health and safety, relationship with the owner, and technology.

To measure management practices we developed a survey for each management dimension. Evaluation questions with a 5-point Likert qualitative scale of response ranging from 1: Strongly disagree to 5: Completely agree with the question statement were used. A weighted average of each dimension was used to score the practices.

The companies surveyed were part of the “Collaborative Building Excellence Group” that works with the GEPUC. Surveys were applied via Internet to management staff members of the companies, from the CEO to project managers. Response rates obtained were greater than 60% in all cases, which was good enough to get a 90% of confidence and 5% of error of the sample.

KEY PERFORMANCE INDICATORS SURVEY

The performance evaluation was based on project KPIs used as leading or process indicators. A survey among 21 project managers of the construction companies was conducted to prioritize 9 KPIs out of a 23 literature review list. The selection criterions were: importance for the monitoring of projects and the availability of information to calculate them. The selected group of KPIs include: cost deviation, schedule deviation, accident frequency index, accident gravity index, and planning effectiveness, constraint release, quality index, productivity and contract change.

Project managers of 41 construction projects during three months filled the form containing the 9 KPIs. Projects having at least 3 months advanced and with at least 3 months before ending were chosen.

SOCIAL NETWORK ANALYSIS

SNA was used for understanding the pattern of relationships within the organizations. The analysis allowed to determine if the social networks are tightly bounded diversified or constricted, to find its density and clustering (Abraham, et al., 2009). Some measures as density, diameter, and average path length are used as indicators to understand how the network structure is related to project performance and management practices. These measurements let us see how far the nodes are from each other and how easy are the communication between them.

CORRELATION ANALYSIS

Analysis of Shapiro-Wilk normality was applied to data obtained in management practices, network surveys and records of KPIs. Pearson correlation index **r** was used to measure how related were the sets of data that presented normal distribution. Spearman correlation analysis was applied to non-normal series after ranking raw data. We describe the strength of the correlation using the guide that (Evans, 2012) suggests for the absolute value of r: 0.00-.19 “very weak”; 0.20-.39 “weak”; 0.40-.59 “moderate”; 0.60-.79 “strong”; 0.80-1.0 “very strong”.

Free software R version 3.1.2 (2014-10-31) was used to obtain the correlations. Only strong (0.6<= r < 0.8) and very strong (r =>0.8) correlation values, independent of the sign, are shown ahead. The corresponding significance of pairwise p value for each variable equal to 0.05 or less is considered a high significance relationship.

RESULTS

The results are divided into three groups: first relationship between management practices and project performance, second relationship between organization and project performance and third the relationship between management practices and organization. Here some highlights of the results are presented within each area.

MANAGEMENT PRACTICES AND PROJECT PERFORMANCE.

Correlation was used to measure linear dependence between each management dimension score and the variability of each project KPI. Standard Deviation (SD) was used as measure of process variability. We calculated the standard deviation of each KPI using data from all projects in each company. Since variability is considered production enemy, low variability is assessed as good. Results are shown in Table 1.

Table 1: Correlation for KPI variability vs management dimension development.

Management practice	KPI	Pearson-r	p-value
Innovation	Schedule deviation	-0.840	0.005
Technology	Schedule deviation	0.824	0.006
		Spearman-r	**p-value**

Labor health & safety	Accident frequency	0.920	0.000
Labor health & safety	Accident gravity	0.803	0.009

Additionally, relationship between management dimensions weighted average score and the median of each project KPI were calculated. We present the results in Table 2.

Table 2: Correlation between KPI median and management practices scores.

Management practice	KPI	Pearson-r	p-value
Relationship with owner	Planning effectiveness	0.748	0.033
		Spearman-r	**p-value**
Quality	Contract bid change	0.778	0.014
Communication & information	Quality index	0.943	0.005
Costs & schedule	Quality index	0.943	0.005
Planning & programing	Constraint release	0.753	0.019

Quality KPI is very strongly correlated to communication & information and costs & schedule management. Also, labor & health safety management has very strong relation to accident frequency and gravity indexes. As well schedule deviation has very strong inverse correlation with innovation management. On the other hand curiously, schedule deviation variability is directly related to technology management.

ORGANIZATION AND PROJECT PERFORMANCE

Organization was analyzed as social network inside the company. Some properties of the network are related to easy information movement and other ones are related to confidence and commitment (Alarcón, et al., 2013; Pentland, 2014). Correlations between social networks metrics and project KPIs median are detailed in Table 3.

Table 3: Network metrics vs KPI median correlation

Network metric	KPI	Pearson-r	p-value
Relevant Information Exchange-Mean degree	Planning effectiveness	0.995	0.005
		Spearman-r	**p-value**
Frequent Interaction-Density	Accident frequency	-0.975	0.005
Full Interaction-Density	Accident frequency	-0.975	0.005
Innovation development-Density	Accident frequency	-0.975	0.005
Personal Confidence-Density	Accident frequency	-0.975	0.005
Planning and Problem Solving-Density	Accident frequency	-0.975	0.005
Relevant Information Exchange-Density	Accident frequency	-0.975	0.005
Personal Confidence-Diameter	Accident frequency	0.947	0.014
Frequent Interaction- Mean degree	Contract bid change	-0.900	0.037
Planning and Problem Solving-Mean degree	Contract bid change	-0.900	0.037
Frequent Interaction- Path length	Accident frequency	0.975	0.005
Full Interaction-Path length	Accident frequency	0.975	0.005
Personal Confidence-Path length	Accident frequency	0.975	0.005
Planning and Problem Solving-Path length	Accident frequency	0.975	0.005
Relevant Information Exchange-Path length	Accident frequency	0.975	0.005

KPIs variability was correlated to networks metrics as we try to find ties between organization characteristics and project performance. Main correlations are shown in Table 4.

Table 4: Network metrics and KPIs variability correlation.

Network metric	KPI	Pearson-r	p-value
Innovation development-Path length	Planning effectiveness	-0.893	0.042
Innovation development-Diameter	Planning effectiveness	-0.908	0.033
Full Interaction-Diameter	Productivity	0.938	0.018
		Spearman-r	**p-value**
Frequent Interaction-Density	Contract bid change	0.900	0.037
Full Interaction-Density	Contract bid change	0.900	0.037
Innovation development-Density	Contract bid change	0.900	0.037
Personal Confidence-Density	Contract bid change	0.900	0.037
Planning and Problem Solving-Density	Contract bid change	0.900	0.037
Relevant Information Exchange-Density	Contract bid change	0.900	0.037
Frequent Interaction-Diameter	Contract bid change	-0.949	0.014
Full Interaction-Diameter	Contract bid change	-0.894	0.041
Planning and Problem Solving-Diameter	Contract bid change	-0.949	0.014
Innovation development –Diameter	Accident frequency	-0.975	0.005
Frequent Interaction –Diameter	Accident gravity	-0.949	0.014
Planning and Problem Solving –Diameter	Accident gravity	-0.949	0.014
Full Interaction-Mean degree	Accident gravity	-0.900	0.037
Relevant Information Exchange-Mean degree	Accident gravity	-0.900	0.037
Frequent Interaction-Path length	Contract bid change	-0.900	0.037
Full Interaction-Path length	Contract bid change	-0.900	0.037
Personal Confidence-Path length	Contract bid change	-0.900	0.037
Planning and Problem Solving-Path length	Contract bid change	-0.900	0.037
Relevant Information Exchange-Path length	Contract bid change	-0.900	0.037
Innovation development-Path length	Accident frequency	-1.000	0.000
Innovation development-Path length	Accident gravity	-0.900	0.037

Innovation development network, by its path length, is correlated to accident gravity, accident frequency and planning effectiveness. All are inverse relations, so a large path length corresponds to a worst project performance.

MANAGEMENT PRACTICES AND ORGANIZATION

Networks included in the analysis were: personal planning & problem solving, confidence, innovation development, full Interaction, frequent interaction and relevant information exchange.

Mean degree is the number of edges connected to each node in the network and is related to the ability to communicate. It is closely related to the density of a network. We found out that personal confidence and innovation development networks mean degree is very strongly correlated to leadership and suppliers management. Also innovation management is strongly correlated to relevant information exchange network mean degree. So far network metrics are strongly correlated to leadership, suppliers, planning and programing, innovation and labor health and safety management.

Table 5: Management practices score vs network metrics correlation.

Management practice	Network metric	Pearson-r	p-value
Planning & programing	Relevant Information Exchange-Diameter	-0.947	0.015
Labor health & safety	Innovation development-Diameter	-0.885	0.046
Innovation	Relevant Information Exchange-Mean degree	0.915	0.030
Leadership	Innovation development-Mean degree	0.909	0.032
Leadership	Personal Confidence-Mean degree	0.912	0.031
Suppliers	Innovation development-Mean degree	0.908	0.033
Suppliers	Personal Confidence-Mean degree	0.924	0.025

A summary of the relationship between project performance, organization characteristics and management practices is shown in Figure 1 as a network.

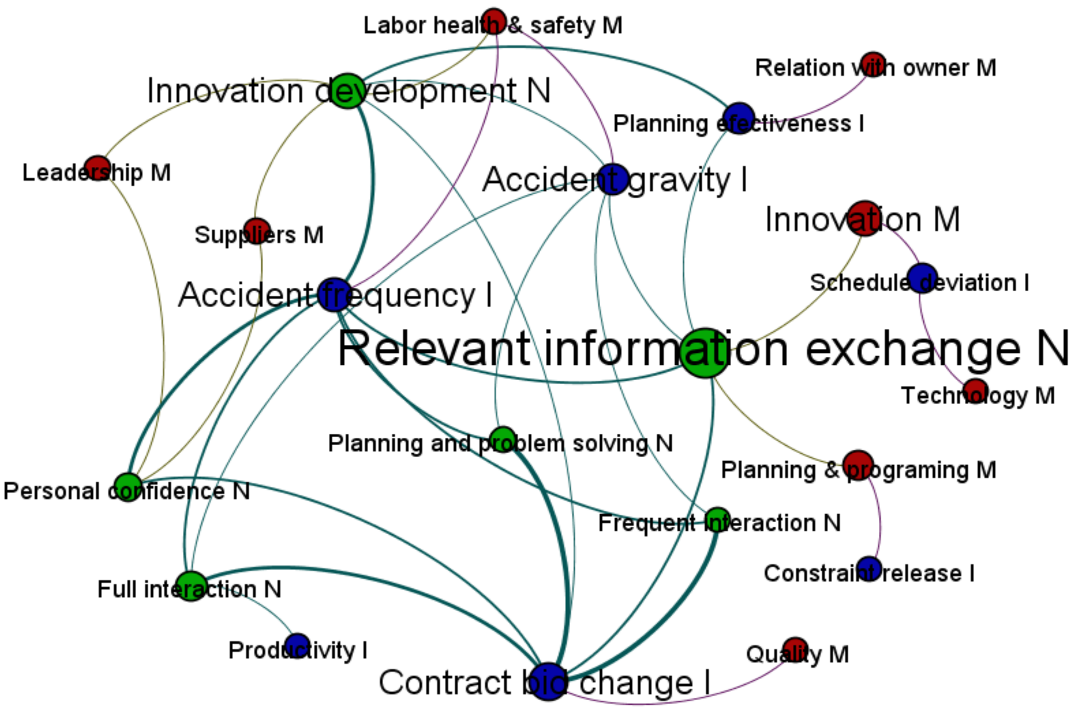

Figure 1: Relations between management practices, social networks and project performance

Management practices (M), social networks (N) and project performance indexes (I) are represented by circular red, blue and green nodes respectively. Bigger nodes correspond to high betweenness centrality and have a large influence on the flow of items through the network. The links appear as lines of different thicknesses depending on the number of times it has been identified a link between nodes. Pearson or Spearman r index were used to represent tie weight. Gephi 0.8.2 Beta free software was used to create de diagram showing correlations.

In Figure 1, relevant information and innovation development social networks appear as a structure that has direct or indirect ties with most indexes and dimensions of management. Contract bid change, accident gravity and accident frequency project indexes seem to summon the efforts of all internal factors in these companies.

CONCLUSIONS

Our research aimed to establish the existence of significant relationships between management practices of construction companies with its organization and the results obtained in their projects. It was found that organization social networks are the basic structure to which the projects performance indexes and management practices scores are significantly related.

High scores in management practices are associated with better performance KPIs in projects. Into the group of construction enterprises eight out of fifteen management dimensions were related to project KPIs mainly quality, accident-ability, planning and project scope indexes. This kind of relation between management practices and enterprise performance have been established previously in construction industry (Ramirez, Alarcón, and Knights, 2004). Improving management practices should improve enterprise outcomes as was demonstrated in other industries (Bloom, et al., 2011). The inverse relation between schedule deviation variability and technology management may be due to weak degree of readiness of users as reported in the surveys. It is well known that technology readiness is a moderator to organization performance (Kuo, 2013).

Higher densities of the social networks are associated with better performance indicators. Instead long lengths in diameter or path length are correlated with low KPI values in projects. This confirms that the strength of an individual’s social group is positively associated to better performance indicators as productivity because it enhances the information flow (Pentland, 2014). For Lean Construction project management, information flow affects all other resources significantly (Dave, et al., 2010). Implementation of the LPS, for example, has demonstrated to play a role in strengthening social networks among the project participants (Priven and Sacks, 2013). In addition, improving employee social networks may increase access to timely information while also reducing monitoring costs (Adler and Kwon, 2002).

The better average degree of social networks is associated with high development of the dimensions of management in the organizations. On the other hand long distance communication among members of the corporation, measured by the diameter or path length, is associated with low scores of management practices. It is known the link between management planning and programming with the network of relevant information (Dave, et al., 2010). Our findings confirm an important relationship between supplier management and the networks of innovation (Morledge, 2011).

Based in results presented herein we recommend that managers in construction enterprises take a holistic approach for strategies of improvement considering the complex system shown in figure 1. Social networks must be regarded since they are bridging most of the management practices with KPIs and its characteristics are strongly related to better project performance.

The results shown provide an objective basis for relating the performance of projects with organization and management in the construction companies. It not only enhances the understanding of the relation between these variables but also sets a base for managers to measure, monitor, and improve the existing performance of their enterprises and projects.

We are limited to portray the conditions of the companies investigated. Our results represent a temporal reality bounded by the study period of the projects. As social structure evolves during the runtime of projects, a time line tracking should be done to provide better information for management strategies. Causality between network characteristics and management dimensions development should be established too.

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USING APPRECIATIVE INQUIRY AS A STRATEGY TO ACCELERATE TEAM BUILDING ON SITE

Ignacio Pavez[1], Luis F. Alarcón[2], and Jose L. Salvatierra[3]

ABSTRACT

Current team building models has been designed using traditional organization development practices, which has not been proven to be effective for accelerating the process of team formation. Therefore, we designed a study aimed to contrast two different strategies of team development, in order to compare their capacity to speed up the process of team building on-site. The first strategy was based on the traditional team building approach and the second was based on appreciative inquiry (AI), which is a strength-based process of organizational development and change. We used grounded theory methods to conduct a systematic comparison of 10 construction project teams, which were randomly assigned to either the strength-based team development intervention (based on AI) or to the traditional one (based on Dyer' model of team building). Data collected from three different sources (face-to-face interviews, field notes and observations) provided strong evidence that the strength-based process of team development is better to accelerate the process of team formation, especially at the early stages of a construction project. To consolidate the outcomes of this study, we created a strength-based model of team development (called P-ICIA), which offers some interesting insights to enrich team development research and practice.

KEYWORDS

Team building, appreciative inquiry, strength-based change, trust, collaboration.

INTRODUCTION

Experience has shown that there is a direct relationship between the final outcome of a project and the capacity/quality of the project management team (Dainty, Cheng and Moore, 2005; Pavez, 2007). Therefore, organizations have created a growing need to thoroughly understand team design, interaction and development (Klein et al., 2009; Millhiser, Coen and Solow, 2011).

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Currently, team development has become a recognized technique in the field of organizational development (French and Bell, 2001), which accounts for its permanent use by consultants, scholars and researchers. Team development interventions have evolved from an approach focused on solving problems (traditional model) to the study of exceptional performances, which promote the development of social systems through the enhancement and cultivation of strengths (Cooperrider, Whitney and Stavros, 2008). Given the differences between traditional and positive forms of team development, this research has been designed to compare the capacity of both models to speed up the process of team building on-site. To accomplish that goal, we used grounded theory methods (Glaser and Strauss, 2009) to carry out a systematic comparison of 10 construction project teams, which are part of a group of Chilean construction companies that currently conducts research in partnership with the *Centro de Excelencia en Gestión de Producción de la Pontificia Universidad Católica* (GEPUC) [Center for Excellence in Production Management at Pontifical Catholic University of Chile]. Those teams were randomly assigned to either the strength-based team development intervention (based on appreciative inquiry) (Cooperrider and Srivastva, 1987; Whitney et al., 2004) or to the traditional one (based on Dyer' model of team building) (Dyer, 1987).

THEORETICAL BACKGROUND

Team building has been described as one of the most popular intervention techniques in the field of organization development (OD) (Buller and Bell, 1986; Klein et al., 2009; Salas, Rozell, Mullen and Driskell, 1999). The main objective of a team building process is to increase the effectiveness of work teams. This is achieved by a process that allows team members effectively acquiring new skills and perceptions to produce a simultaneous change in interpersonal relations and performance (Buller and Bell, 1986).Team building embraces the central notion that enlisting the participation of team members in planning and implementing their own change will be more effective than simply imposing change on the team from outside (Salas et al., 1999). Thus, the foundation of the team building process is closely related to the principles that guide any OD intervention. A team building intervention has a clear methodological basis (specific steps) but the focus or the topics for change might vary based on the purpose of the process, the team composition (diversity of team members), the nature of the team (e.g. stable teams, temporary teams, or inter-organizational teams), and the context in which the intervention is carried out, among others (Klein et al., 2009).

Therefore, we selected team building approaches that were distinctive in terms of the process that characterize each methodology. Taking into account that criteria, we selected two models/approaches of team development: 1) Dyer's model of team building (Dyer, 1987; Dyer, Dyer and Dyer, 2013) and 2) the appreciative team building approach (Bushe and Coetzer, 1995; Whitney et al., 2004). We chose Dyer's model of team building because is the one that best resembles the classic mode of action-research (focused on problems). On the other hand, we chose the appreciative team building model because it proposes a new to way to addresses the process of team development, which is focused on leveraging the strengths of the social system.

DYER'S MODEL OF TEAM BUILDING

Dyer's model of team building is probably one of the best known approaches of team development under the problem-solving framework. This model is a great representation of the traditional mode of action-research, which starts with a diagnosis and ends with an evaluation of the main learnings and the effectiveness of the intervention (Susman and Evered, 1978). Grounded on the traditional approach of action research, Dyer's model of team building is described as follows: "Ordinarily a team-building program follows a cycle similar to that depicted in Figure 1.A. The program begins because someone recognizes a problem or problems. Either before or during the teambuilding effort, data are gathered to determine the root causes of the problem. The data are then analyzed, and a diagnosis is made of what is wrong and what is causing the problem. After the diagnosis, the team engages in appropriate planning and problem solving. Actions are planned and assignments made. The plans are then put into action and the results honestly evaluated."

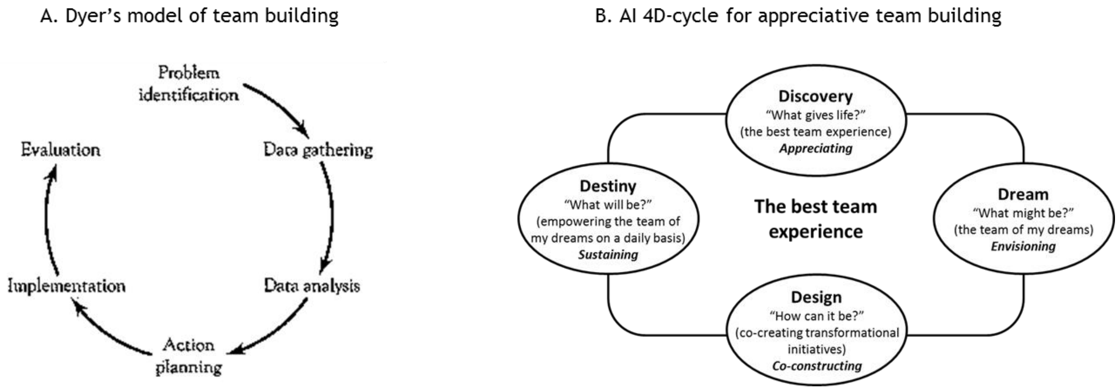

Figure 1: The two approaches of team development.

APPRECIATIVE TEAM BUILDING

Appreciative team building (ATB) is an approach of team development grounded on the application of AI (Cooperrider and Srivastva, 1987) as the methodological basis for change (Bushe and Coetzer, 1995; Whitney et al., 2004). AI is both a method of action research and a theory of how social systems develop and evolve, which rethinks the foundations of OD. In particular, it challenges the assumption that the purpose of an OD intervention is to solve a problem, because under that paradigm, groups and organizations are treated not only as if they have problems, but as if they are problems to be "solved." Instead, AI invites to rethink the practice of OD through the following question: What if, instead of seeing organizations as problems to be solved, we saw them as miracles to be appreciated? How would our methods of inquiry and our theories of organizing be different?. This re-formulation of the symbolic interpretation of social systems constitutes the basis of this new form of action-research which, stood on the shoulders of social constructionism, can be defined as "the cooperative co-evolutionary search for the best in people, their organizations, and the world around them. As a team building approach, AI embraces the premise that all teams have images of themselves that underlay self-organizing processes and that social systems have a natural tendency to evolve toward the most positive images held by their members (Bushe and Coetzer, 1995). Therefore, ATB can be defined as a praxis of collective action aimed to positively transform the team to its most promising and positive future. From a practical standpoint ATB follows the traditional AI 4-D cycle (Discovery, Dream, Design and Destiny – See Figure 1.B).

RESEARCH METHOD

RESEARCH QUESTIONS AND OBJECTIVES

The research questions central to this study is: How to accelerate the process of team formation on site? Based on those questions, this research has four main objectives: (1) To compare a traditional team building approach with a strength-based approach of team development; (2) To assess the effect of each approach into the process of team development; (3) To explore which approach is more effective for the process of team formation; and (4) To produce a model of team development that will help accelerating the process of team formation on site.

SAMPLE

The study was carried out with construction project teams belonging to 5 different Chilean medium-size construction companies. The unit of analysis was the construction project team and participants were people who belong to 10 different teams. The average size of a team varied from 5 to 14 people, based on the type and the stage of the construction project. The research was carried out at the construction site, in order to work with and observe teams in their natural setting. We selected 10 teams that embraced diversity in terms of the variables that might have a higher influence in team dynamics: type of construction project, type of contract, ownership of the project, project duration, project stage, and team performance. Then, we formed 5 pairs of teams that matched in one or more variables, in order to have similar groups of teams implementing the two types of intervention. After that, we used a randomized paired design for the intervention, which means that, within a pair, we randomly assigned one team to the strength-based team development cohort and one team to the problem-based (or traditional) team development cohort.

DATA COLLECTION

The research team collected data over a 4-month period, from April 2014 to July 2014 and consisted of field notes, face-to-face interviews and group observations. Field notes were focused on registering the activities and outcomes of each team development session. All team sessions were audio or video recorded, in order to have a complete record of the activities and outcomes of the intervention process. We implemented 5 sessions with each team, so we carried out 50 sessions in total (25 for each type of intervention). Data analyzed were equivalent to approximately 5345 minutes of team development work. Face-to-face interviews focused on eliciting lengthy narratives detailing participants' actions, thoughts, feelings, and social interactions that occurred to them during the team development process. Special effort was made to trigger vivid recollections of team members' experiences on each stage of the process; so one interview protocol was prepared for each team development intervention. Interviews lasted between 30 and 70 minutes and all of them were transcribed by the research team. We did 16 interviews for each methodology. Finally, group observations were used to generate data about team interactions as they naturally occurred in each team development session. They were focused on the social dynamics deployed by teams during the intervention, including observer's interpretations based on the analysis of the body language and other emotional expressions. We produced full observation records of 4 randomly selected teams (2 teams per intervention method). Each team was observed using the same observation protocol, which was focused on perceived power distance, positive and negative interactions, team member roles, and group norms.

DATA ANALYSIS

The audio recording for each interview and the video/audio recording for each session was reviewed multiple times, and each transcript was read repeatedly. The procedure of data analysis followed the four-stage procedure of grounded theory's constant comparative method (Glaser and Strauss, 2009): (1) comparing incidents applicable to each category; (2) integrating categories and their properties; (3) delimiting the theory; and (4) writing the theory. During the first stage, all transcripts (field notes, interviews and observations) were first coded using "open-coding" techniques, which involve rigorous line-by-line examination of every transcript to identify "codable moments" or segments of text with potential research significance (Corbin and Strauss, 2007). This process resulted in the identification of 480 fragments of text that were sorted on the basis of similarity into 112 initial categories. After the open coding an initial codebook for each methodology was developed. The initial codebook of Dyer's methodology consisted of 18 categories, and the initial codebook of the ATB methodology consisted of 16 categories. The whole coding process was carried out collaboratively by the research team using Dedoose. See Pavez (2014), for a detailed description of categories and properties. Theory delimitation started to take place when underlying uniformities in the original set of categories and/or properties were discovered. Thus, we started to delimitate the theory by using a small set of higher-level concepts. In doing so, first-order codes were grouped according to their similarity and second-order codes (higher-level concepts) were created (Saldaña, 2012). Finally, theory formulation occurred in a developmental way. A continuing process of data analysis and literature review informed several adjustments of the initial conceptual model to provide theoretical support of discovered variables. Tacking back and forth between the data, research materials, literature, and the original conceptual model, a grounded theory of a model of team development that accelerates the process of team formation on site emerged.

FINDINGS

The goal of this study was to characterize a team development process that would help to accelerate the process of team formation on site. Data suggest that the ATB model works better than the traditional approach, because of three key findings related to group behavior which are described as follows:

PATTERN 1: A REVERSAL FOCUS OF GROUP NEEDS CONSIDERATION

Data coming from the analysis of the outcomes of every team meeting—which were focused on the dialogues, agreements and deliverables of every stage of the process—showed an interesting pattern. It was clear that instrumental (task-related) and expressive (interpersonal-related) needs were present in all teams and they tried to fulfil both during the process of team development. However, the time when those needs appeared—which reflects the focus of team interactions during the intervention process—was different for both types of interventions.

Dyer's model of team development

During the initial stages of the problem-solving approach (problem identification and data collection) the team was primarily focused on task-related needs. This means that most conversations, interactions and the collective processes of sense-making, were focused on understanding some gaps in productivity, the availability of resources, the organization of the work, the planning process and/or the coordination among different work-groups. The analysis of those gaps was translated into key areas of work for each team, which repeatedly included: lack of good economic incentives, lack of organization and planning, lack of efficacy in team meetings, and the need for improvement in some relational dynamics (e.g. leadership, communication and decision making). As teams got to understand the root causes of the problems, the expressive (or socio-emotional) needs of the group emerged. This happened because teams had to deal with three important relational issues: acknowledging different viewpoints, managing conflicts, and generating agreement among team members. Finally, in order to solve their problems, teams had to create an action plan and then to implement it. At this stage of the process, the initiatives were mainly focused on solving the relational issues that prevented the team to get the desired results. Therefore, at the end of the process, the team was primarily oriented to address (and work on) its expressive needs.

Appreciative team building

During the ATB intervention the focus went in the opposite direction regarding the time frame in which instrumental and expressive needs were addressed. At the *discovery phase*, most stories about the best team experience were based on emotional memories about relationships, human values, recognition, friendship and individual valuation. Consequently, conversations were mostly focused on sharing and revealing expressive needs. During the *dream phase*, most images of the ideal future and/or the "ideal team" were based on rich narratives of team achievements and how they should approach work. Consequently, conversations focused more on sharing and revealing the instrumental needs of the team. At the *design phase*, each team worked on crafting a more concrete version of the desired future by devising one or two specific statements related to some important elements of team dynamics: 1) goals or purpose, 2) roles and responsibilities, 3) relationships, 4) procedures, 5) leadership, 6) team spirit, 7) productivity and performance, and 8) communication (Cooperrider, Whitney and Stavros, 2008; Whitney et al., 2004). At this phase, the focus was slightly oriented to instrumental needs, but it was possible to see more balance. This happened because teams integrated the main elements of both the best team experience (discovery) and the ideal team (dream). Finally, the *destiny phase* was dedicated to create and implement some change initiatives that would help the team reaching the ideal future. Here, teams included both instrumental and expressive needs (slightly loaded to instrumental needs). In summary, it was possible to observe that both methodologies went into opposite directions in terms of the time frame in which they addressed the expressive and instrumental needs of the team. The problem-solving approach started with great attention to instrumental needs and it ended up shifting that focus to expressive needs. On the other hand, the ATB approach started by giving great attention to expressive needs, then it shifted to instrumental needs, and it ended up balancing both of them.

PATTERN 2: DISTINCTIVE DYNAMICS OF GROUP PROGRESSION

Data collected from interviews, which focused on eliciting lengthy narratives detailing participants' actions, thoughts, feelings, and social interactions that occurred to them during the team development process, showed another interesting pattern. The later stages of the coding process (second-order coding) naturally converged into a set of themes that progressively appeared during the team building process. This resembled what previous studies in this area has shown, which tell us that groups engage in an identifiable set of activities, during different periods of time, that can be categorized as stages or phases of group development (Tuckman, 1965; Miller, 2003).

The content and focus of team interactions, however, were different for both methodologies. Dyer's problem solving approach followed a very similar pattern compared to traditional team building models. This pattern can be characterized as restorative dynamics oriented to remove the problems that are blocking the development of the team. We called this pattern "fix to develop", because the team explored their major problems in detail and, after that, they developed the required skills to overcome those challenges together. On the other hand, the collection of team member experiences on each stage of the ATB process helped to observe a different pattern of group progression compared to the problem-solving approach. The main characteristic of this pattern was the nurturing dynamics of team interactions that propelled team development. We called this pattern "nurture to grow", because as teams moved along the ATB process, upward spirals of positive interactions helped the teams growing in the direction they wanted. During the process of data analysis, the codes naturally converged into four different, and unique, progressive stages when compared to the conventional models of group development. These stages were named illumination, connection, inspiration, and achievement. These stages represent the highest level of abstraction for the categories generated during the coding process; and each of them included well-defined properties (Corbin and Strauss, 2007; Glaser and Strauss, 2009). Interestingly, in none of those stages conflict resolution appeared as central aspect of group development.

PATTERN 3: POSITIVITY AS THE ENGINE OF THE DEVELOPMENTAL PROCESS

Analysis of the data showed that only one variable remained stable in both types of interventions. That variable was the positive affective tone of the team (PATT), which can be described as the shared pattern of consistent (or homogeneous) positive affective reactions (George, 1990). However, this only occurred during the ATB intervention. The PATT came out constantly and with great frequency during the process of analysis of each source of data. This helped to explain the upwards spirals of generative interactions that aided teams (under the ATB methodology) growing in the direction that they wanted.

As we previously stated, we called this dynamic "nurture to grow", because the team had to nourish itself to sustain the transformational energy that this process required. The nutrients of the system, in this case, were the positive emotions that the ATB intervention sparked on every team member; which were transformed into the

PATT trough the diffusion of those feelings. At the beginning, positivity was mainly sparked by the facilitator using the tools that AI provides (e.g. appreciative interview and visioning exercise). However, as the process continued, the team started to integrate that element into their natural encounters. Initially, focusing on the positive was something new for the team, but when they were able to understand and integrate those concepts, they started to leverage and intensify positivity as a tool to develop and grow as a team.

THE P-ICIA: A MODEL OF TEAM DEVELOPMENT THAT ACCELERATES THE PROCESS OF FORMATION ON SITE

This study contributes to understand team building as a generative phenomenon. In other words, as a process characterized by dynamics of excellence, appreciation and abundance; where the PATT is something regular and stable rather than exceptional. Moreover, our data suggest that these processes of team development works better for accelerating the process of team formation, because it eliminates the need for conflict and resolution (e.g. Tuckman's forming and storming stages) to reach the stage of "performing" (Tuckman, 1965) in a quicker way. This is particularly important for teams that have not previously worked together (as most construction project teams), because for that types of teams take longer to achieve the levels of trust that allow the emergence of good processes of feedback that characterize high performance (Bennis and Shepard, 1956; Tuckman, 1965; Miller, 2003).

This research provides interesting insights into the elements that might characterize a strength-based model of team development, which we propose that accelerates the process of team formation on site for three reasons. First, a strength-based team development approach starts by building strong relationships among team members (expressive needs) and uses that basis to accomplish the instrumental needs of the team (productivity, efficiency and performance). Second, the group progression is characterized by dynamics that nurture positive emotional states, rather than managing conflicts, to increase trust and collective efficacy. In particular, we suggest that a strength-based model of team development starts by *illuminating* the strengths of the team; then relationships are reinforced by increasing the levels of *connectivity*; after that, the team is *inspired* to work in its own transformational process and; finally, the group collectively implement developmental initiatives to *achieve* the desired future and to become the team of their dreams. Third, a strength-based model of team development uses positivity as the engine of the developmental process. This means that positive emotional states are sparked, diffused, and sustained over time to energize the team in its transformational endeavor. Based on the data collected during the process, we created a strength-based model of team development called P-ICIA (positive affect-P; illumination-I; connection-C; inspiration-I; achievement-A). The model is presented in Figure 2.

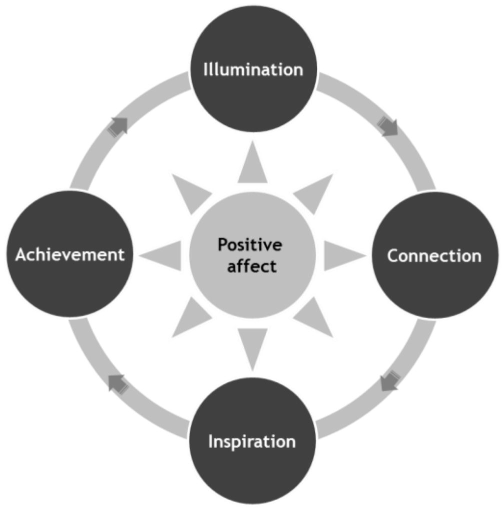

Figure 2: The P-ICIA model of strength-based team development (Pavez, 2014).

CONCLUSIONS

The results presented in this article show that there is a vast potential to improve the performance of construction project teams, which is simply wasted by not considering the team development process as a critical activity for project execution. This represents a latent opportunity for organizations where Lean is part of their strategies, because in these types of companies people are the key to success (Pavez, 2007). Based on lessons learned from the participants' experiences, some initiatives that can facilitate and/or improve teamwork at the construction site are the following: (1) Organizing work meetings with instances to execute team activities: As our study shows, this activities will have more impact on accelerating the process of team formation if they are carried out at early stages of the project and using a positive approach (i.e. ATB or similar); (2) Establishing structures and/or incentives that encourage the implementation of team development practices: This element strongly appeared when we talked to participants about how to sustain the level of teamwork that they reached as a consequence of the intervention process; and (3) Incorporating qualified professionals who can support team formation and development: This conclusion came out from the analysis that participants made about the role of the facilitator (researcher). Participants found value in having an external expert that would help the team to progress and to keep the focus on teamwork. Thus, they called for replicating this strategy at the beginning of each project, but ideally using internal staff. Finally, the main limitation of this study was the aim of studying the process of team development rather than its results.

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USING ORGANIZATIONAL MODELING TO ASSESS THE IMPACT OF LEAN CONSTRUCTION PRINCIPLES ON PROJECT PERFORMANCE

Marcelo Concha[1], Luis Fernando Alarcón[2], Claudio Mourgues[3] and José Luis Salvatierra[4]

ABSTRACT

This article delves the use of organization modeling to assess the impact of Lean construction concepts on project performance. The research calibrated four virtual models of construction project organizations developed using the Virtual Design Team (VDT) method and SimVision® VDT computational tool. The models were validated comparing their predictions with actual results obtained in the projects, and the assessment and approval of technical experts of the companies in the study.

Then, the four models were used to evaluate the impact on project performance using alternative organizational designs, each of them inspired in Lean production concepts and principles.

The results proved that VDT models can be used to evaluate the impact of the Lean concepts in projects performance, representing these notions in the organizational design and showing the benefits of implementing them. In general, the models predicted positive impact in terms of cost, time, variability and waste reduction in organizations inspired by Lean principles and concepts. These outcomes contribute to expand the uses of VDT methodology, proposing a method to include Lean principles in the organization design, and allowing companies to model Lean Project Management concepts at the planning and design phase, achieving improvements in terms of cost, schedule and variability.

KEYWORDS

IGLC23, organizational design, VDT, lean Construction.

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INTRODUCTION

The Stanford Center for Integrated Facility Engineering (CIFE) has developed a methodology to help companies design project organizations, being part of progress in terms of industrial design. This methodology is based on the assumption that the primary development work is the knowledge about it and coordination: both are seen as information processing activities (Galbraith, 1974) and communication. These efforts resulted in a modeling system called Virtual Design Team (VDT), in which rational agents process information associated with direct labor, rework, coordination and waiting times for decisions (Levitt and Kunz, 2002). In parallel, a theory of production in which production is established by a set of processing activities and workflow processes that add value (Koskela, 2000) emerged. Although both efforts discussed similar topics - from different perspectives –there is no understanding of how these jobs are linked. For example, understanding the variables of organizational modeling that can represent concepts and principles of the Lean Construction philosophy, displaying their impact in projects and organizations. In this line, the objectives of this study are: firstly to found barriers to the implementation of VDT models in real projects, secondly to propose a way of modeling concepts of Lean Production with VDT, and thirdly to evaluate the impact of Lean Production principles in the project performance through the VDT simulation methodology.

BACKGROUND

Traditional planning analyzes each activity as a transformation process, dividing it into sub-processes, which are done with certain rates of performance. One problem with this approach is the high variability in meeting the expected rates for those sub-processes. Gonzalez and Alarcón (2003) analyzed the programming of buffers in response to this variability in construction. Buffers try to cover spaces that usually occupy rework, project coordination activities and various kinds of contingencies. It showed that buffers help to reduce the impact of variability in projects and a programming buffers methodology in repetitive projects was proposed.

Koskela (2000) proposed a theory of production - Lean Construction - which seeks to reduce the variability of transformation processes incorporating the concept of production as transformation, flow and value generation. The key to this new theory of the production process is in the balance between these three elements.

Several authors have used various methods to assess the impact of Lean in projects or production. For example, Agbulos and Abourizk (2003) simulated drainage maintenance processes under the application of Lean concepts. Their approach was to model the process based on activities that add and not add value. Furthermore, Schroer (2004) used a probabilistic approach in discrete simulation to understand Lean manufacturing principles, using the Modular Manufacturing Simulator. Another study (Ales, Tommelein and Ballard, 2006) introduced the concepts of buffers, batch size, variability and their interactions in a simulation environment (STROBOSCOPE) to model different scenarios, showing how change the cycle times under different configurations. The study showed that in all scenarios, as variability increased, the necessary buffers also increased, as the project duration.

While these and other studies have contributed much to the understanding of Lean Construction and it impacts, their approach from the perspective of processes has shelved organizational aspects of Lean Construction.

Although project organization modeling exists since several years, its adoption has been slow in the construction industry. The Virtual Design Team methodology (VDT) (Levitt and Kunz, 2002; Levitt, 2009) is one of the most important efforts regarding the modeling of project organizations. VDT was created to allow managers and contractors "Designing project organizations as engineers design bridges" (Levitt, and Kunz, 2002), ie, to evaluate multiple organizational alternatives prior to the implementation and to select the best option for the project. This type of analysis has been explored in many studies (Kunz, Levitt and Thomsen, 1997; Levitt and Kunz, 2002; Nissen and Buettner, 2004; Khosraviani and Levitt, 2005; Carroll et al., 2006).

Regarding the operation of VDT, this methodology identifies four fundamental probabilities that determine the different levels of information processing within the organization, in terms of direct labor (direct work and rework of project activities), exceptions and decision-making processes (coordination between workers of activities that are connected in terms of information, and decision waiting times), involving meetings and external noises affecting the daily work. These probabilities are (ePM, 2005): Information Exchange Probability, Noise Probability, Functional Error Probability and Project Error Probability.

Based on the Contingency Theory (Galbraith, 1974), which states that organizations must adapt projects to project environment, and based on the extensive literature on organizational design, VDT defines four key aspects to incorporate the features of organizations: Team Experience, Centralization, Formalization and Matrix Strength. In addition, VDT considers a number of variables that allow modeling, for example, the experience of workers or the uncertainty of the information necessary to perform an activity. The representation of VDT processes allows including transformation and flow processes, with considerations of the value generated by them. Table 1 shows the elements under the VDT modeling methodology and its relationship with Lean processes.

Table 1: Types of Labor Division in VDT and its association with transformation, flow and value added processes.

VDT elements	**Lean Construction elements**			
	Transformation	Flow	Value	No Value
Direct work	x		x	
Rework		x		x
Coordination		x		x
Decision wait		x		x

RESEARCH METHODOLOGY

The research methodology consisted in three main phases: VDT methodology calibration for study cases of Chilean projects, the definition of Lean principles representation in the VDT environment and assessing the impact of these principles in projects (Figure 1). SimVision® VDT tool was used to run simulations. SimVision® allows to model organizations and projects: the hierarchy map, activities that have to be done by workers, links between activities representing rework and coordination, type of workers and their skills, meetings, milestones, financial data of projects and caracteristics of an organization, such Centralization and Formalization.

The first phase (calibration) was necessary because the VDT methodology has not been previously applied to projects in Chile. This is relevant because some modeling variables are susceptible to cultural issues and results can differ between countries based on local conditions, such economy, laws, among others. The study cases are four projects of a traditional building construction company (Company A). Initially, the relevant variables were selected for calibration and then the necessary data was assembled. The variables were selected through simulating different organizations on SimVision and analyzing different combinations of parameters and variables. After a deep analysis, it was detected that the variables that most affect in representation of an organization through VDT are the 4 probabilities and all the parameters related to them. Collection of these data was performed through interviews, field visits, obtaining tender files with project information and a survey to collect information related to the input parameters of SimVision® and flow processes. Finally, they were created and simulated models for calibration and modeling. Note that before, during and after the process of data collection, difficulties in the sector, - technical and related to the dedication to research participation - were detected. The second phase of the methodology was to define a way to represent the Lean concepts and principles on VDT modeling environment. Finally, the third phase was to simulate the models created and evaluate the impact of Lean principles in carrying out study cases.

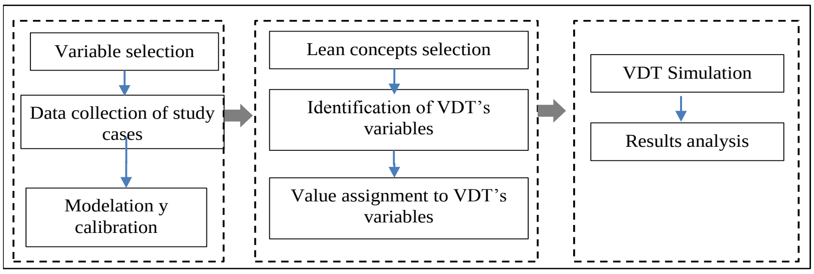

Figure 1: Stages and activities of research methodology.

VDT CALIBRATION AND IMPLEMENTATION BARRIERS

The entry probabilities initially used were obtained from a study of VDT (Ibrahim and Nissen, 2004), which obtained probabilities for Information Exchange 0.7, 0.2 for Noise, 0.05 for Functional Error and 0.05 for Project Error. In general, calibration consisted of modeling projects with fixed initial amounts of work, based on the probabilities of that study, then go modifying until the Cost and Time of each model is adjusted to actual performance in each case with a maximum error margin set at 5%. This limit was set in order to have an adequate margin of error does not exceed the possible profits of projects, commonly defined between an 8 and 15% depending on project type. The results of the calibration are shown in Table 2 (Concha and Alarcon, 2014). Those results were subjected to approval of professional technical management and planning of each company, through a structured interview to assess the quality of the predictions of 14 aspects of time, cost, quality and representativeness of links interactions from the simulation environment (for further information about the specific aspects, see Concha and Alarcón (2014)). The answers were based on how well the models predict real projects results, according to the obtained differences between modeled and real performance, and also under the judgment of each professional regarding the prediction of each model makes sense to the observed on the field.

Table 2: Probabilities calibration results.

Probability of calibrated VDT	Company A
Probability of Information Exchange	0.733
Probability of Noise	0.300
Probability of Functional Error	0.080
Probability of Project Error	0.080

The results of surveys grouped responses of the four projects, in total, 56 predictions. Respondents were four professionals of Company A (Finance Manager, Technical Manager, Head of Quality Management, Head of Planning). The survey scale was the follow: **N / A (Not Applicable)** is marked when the queried feature is unrelated to the investigation or study it was not possible. **Very Poor:** Marked when the model prediction is totally different from reality. In quantitative terms, when far more than 70% of actual results. In terms of plotted parameters when the prediction is 3 categories above or below the actual result (usually there are 4 categories, green level - optimal, yellow level - normal orange level - warning level red - dangerous level). **Poor:** Marked when the model prediction is considerably different from the reality. In quantitative terms, when it has more than 70% of difference in relation to actual results. In terms of plotted parameters, when the prediction is 2 categories above or below the actual result. **Regular:** dialed when the model prediction is not as close to reality, but not so far. In quantitative terms, when far between 5 and 30% of reality. In terms of plotted parameters, is when the prediction is 1 category different compared to the actual result. **Good:** marked when the model prediction is close to reality, but not as accurate. In quantitative terms, when modeled results are 3 to 5% far from reality. In terms of plotted parameters, it is when the prediction is in the same category as compared to the real result but closer to the lower level or higher than the actual outcome. **Very Good:** Marked when the model prediction is very close to reality. In quantitative terms, when modeled results are 3% far or less of reality. In terms of plotted parameters, it is when the prediction is in the same category as compared to the actual result and when is very close to the actual result.

This survey showed high approval of the calibration results (see Figure 2). The 72% of the answers obtained a positive rating, which means that about 72% of the issues were within 5% difference with real performance, in case of quantitative variables, and within the respective category, in case of qualitative aspects. It is also important to note that the response "Regular" obtained a 14%, achieving an aggregate percentage (adding the other two categories) of 86%, indicating that about 86% of predictions were in limits Regular at least. On the other hand, general aspects which obtained a category "Regular" tended to be those most difficult to measure and to corroborate in practice, such as Quality Product and Quality Process. This tended to encourage professionals to respond to the prediction of these factors was "Regular" when the possible reason behind that might not be as verifiable, except for a rough general opinion of experts in the field.

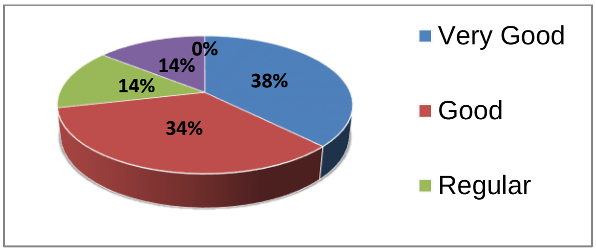

Figure 2: Review of the survey answers from models predictions applied to professionals related with planning.

The aspects most accomplished and evaluated correspond to the capture of the activities that most coordination and rework generated, followed by the cost and time, which generally had positive rating, agreeing with the good results achieved in models relating to these topics. The worst aspects achieved by the models were the "timing" of activities occurrence and the "timing" of the workers backlogs occurrence, because the models failed to predict them at a good way. However, it was not likely they could achieved that, given that the Projects Managers did not follow the Gantt chart in a strict order, so they performed activities to the extent that it could be done, without releasing restrictions to stay on schedule. This realizes the problems with which the sector faces in the local case for deploying virtual models like those in this study (see Table 3), which hinder proper integration of tools. At the date of the paper writing, Company A have implemented Last Planner System to plan projects, so this problem it is partially solved, so better model predictions could be obtained in the future.

LEAN CONCEPTS REPRESENTATION USING VDT METHODOLOGY

The second phase of the research was to define a way of representing Lean principles and concepts using the VDT methodology. This would help to see the impact of applying principles prior to implementation real projects. To this, a list of concepts of Lean Management philosophy was defined, then VDT variables that allow modeling these concepts were identified, and finally values were given to represent these variables VDT with Lean concepts. The list of Lean concepts and principles was defined based on an estimate – made by the researcher – about the possibility of representation through the VDT variables. The values of VDT variables representing the Lean concepts were obtained from interviews with experts in Lean Construction. The interviews consisted on open-ended questions to senior consultants of the Center of Excellence in Production Management UC to see how they interpreted each parameter according to the possibilities of the computer program, based on its experience in counseling. Table 4 summarizes the Lean concepts and their values with VDT variables (Concha and Alarcón, 2014) (Not Applicable = N / A, Low, Medium, High, PM = Project Manager, SL = SubTeam Leader, ST = SubTeam).

After defining the values of the VDT variables for each concept, different scenarios were modeled (VDT values configurations associated with each Lean concept) for the four projects from Company 2. For example, P1 is modeled in each project of Company A, assigning the values shown in the Column 2 in the Table 4. The results of the simulations for each of these projects were compared with the base case of the Company A, obtained during model calibration stage. For purposes of modeling each scenario, the "N/A" assignment in Table 4 means the variable in the base case remains constant.

Table 3: Main barriers detected for the VDT virtual model application in the future in local construction projects.

Problem	Type	Comment
Bad Planning execution	Technical and Management	They don't execute activities as planned. Impossibility to predict results.
Lack of Knowledge Management	Technical/Strategical/Management	Historical information of projects is not used for new projects. Prevents adequately predict cost, schedule, machinery and HH.
Deficient Project Study	Technical	Inadequate use of HH and costs rates, sometimes from other locations out from Chile.
Project Rates used in the Project definition stage are incompatible with VDT models	Technical	Project Resources Rates need to be adjusted to reflect only direct work without rework (adjustments are needed to can use this rates in VDT).
Lack of time and direction to be part of researches.	Strategical	No management that promotes participation in research with HH's supervised and controlled. So far this contribution is voluntary and that downplayed it in terms of priority. Generates excessive times in the process of gathering information.

ASSESSMENT OF LEAN CONCEPTS IMPACTS ON PROJECT PERFORMANCE

In addition to the scenarios associated with Lean concepts set forth in Table 4, three additional concepts were included. They contain contrary aspects to Lean concepts or correspond to a typical misapplication (that do not meet requirements for proper operation). They are multitasking misapplied, flat organization misapplied, and hierarchical organization. Table 5 summarizes the results for each project and concepts in terms of their deviation from Cost and Time with respect to the base case.

It can be see that the impacts vary for each project, which makes sense if you consider the differences between the them, whose peculiarities and special conditions are reflected in differences in the other parameters of the VDT modeling, and consequently, in a different incidence in the Lean concepts implementation. However, a general trend is observed that most of the principles -except the negative scenarios (misapplied multitasking, flatter organizations misapplied and hierarchical organizations)- of the four projects contributed to lower cost and time outputs. Figure 3 shows the average variability within simulations of the projects from the base case. Concerning the principle of creating flatter organizations, illustrating its profit over the base case, which had a structure with some level of hierarchy marked but not as extreme as the hierarchical version (scenario N°11 in the Figure 3). Virtue of a flat organization versus a hierarchical is also appreciated, meaning that when comparing both cases, price and costs tend to be lower in the flat one. On the other hand, it is observed that a flat organization that does not have the trained personnel to make quality decisions (Scenario 10: misapplied flat organization), suffers the consequences in terms of cost and time. In all cases analyzed the cost and time worsened relative to a flat organization that does meet that condition. In addition, there are cases where even worse results are obtained compared to a hierarchical organization, and is understandable, since a hierarchical organization but with good professionals and experienced staff can make better decisions than other flat organization, but with professionals without experience or adequate skills. The quality of decisions is very important and will affect the projects. Another issue of relevance analyzed is multitasking, which reduced all projects cost and time. However, when the functional skills of people are disparate or low in some items (Scenario 9: misapplied multitasking), can cause increases in cost and time compared to a project with people with multitasking, who have high experience and good skills in all items. According to the theory, flexibility and multitasking should involve common denominators in terms of organizational configurations, since having multitasking teams provides flexibility in activities development.

Table 4: Possible VDT inputs involved in the Lean Production concept modelling.

VDT Input /Lean Production Principle	P1 Re-duce waste	P2 Re-duce va-riabi-lity	P3 Redu-ce cycle time	P4 Reduce work batches	P5 Increase flexibility	P6 Stan-dar-dize	P7 Flat Orga-niza-tion	P8 Multi-funcio-nality
Organizational Culture								
Team Experience	High	High	High	High	High	High	High	High
Formalization	N/A	High	High	N/A	Low	N/A	Low	Low
Centralization	N/A	Low	N/A	High	Low	Med. - High	Low	Low
Strength of headquarters	High	N/A	High	High	High	High	High	High
Activities								
Information Uncertainty	Low	Low	Low	Low	Low	Low	Low	N/A
Complexity of requirements	N/A	Low	Low	Low	Low	Low	N/A	Low
Solution complexity	N/A	Low	Low	Low	Low	Low	N/A	Low
Responsible Individuals								
Role of the Professionals	PM	PM	PM	N/A	PM	N/A	PM	N/A
Application experience	High	High	High	N/A	High	N/A	High	High
Ability in an area	High	High	High	N/A	High	N/A	High	Med. or high
Ability in other areas	N/A	Med.	Med.	N/A	Medium or high	N/A	Med. or High	Med. or High

Finally, Figure 4 shows the impact of the scenario "reducing waste" in the amounts of the various processes considered in SimVision®. The value shown is the base case compared with the average of the four projects from Company A, but in all projects were a significant decrease in terms of Rework, Coordination and Wait Decisions Times, activities that do not add value.

Table 5: Percent difference in Duration and Cost for Lean scenarios (8 Lean concepts plus 3 cases of poor Lean applications) as compared to the base case calibrated for each Project.

	Reduce waste	Reduce variability	Reduce cycle time	Reduce work batches	Increase flexibility	Standardization	Flat organizations	Multiskilling	Multiskilling poorly applied	Flat organizations poorly applied	Hierarchical organizations
Project					Difference in Duration (%)						
1	10.2	12.2	11.2	9.4	12.2	9.4	11.6	12.0	-3.5	-28.0	-8.3
2	11.4	17.3	14.4	-6.0	15.9	-5.8	7.5	15.2	-5.6	-77.2	-19.0
3	19.0	22.5	22.0	4.1	23.3	5.6	22.9	23.5	-12.2	-37.8	-38.4
4	8.2	17.1	8.4	10.7	25.4	11.4	21.7	25.6	-6.0	-39.4	-16.4
Average	12.2	17.3	14.0	4.6	19.2	5.1	15.9	19.0	-6.8	-45.6	-20.5
Project					Cost Difference (%)						
1	5.6	8.9	8.0	2.0	9.3	2.0	8.4	6.4	-6.8	-10.5	-9.6
2	2.1	2.0	1.0	-0.3	1.4	-0.2	0.4	1.1	-1.0	-11.8	-8.8
3	16.9	15.2	14.8	3.6	15.0	4.3	17.3	14.5	-4.9	-22.2	-28.7
4	7.0	7.2	7.0	2.1	6.9	2.1	6.7	6.3	-1.4	-9.3	-1.5
Average	7.9	8.3	7.7	1.8	8.1	2.1	8.2	7.1	-3.5	-13.4	-12.1

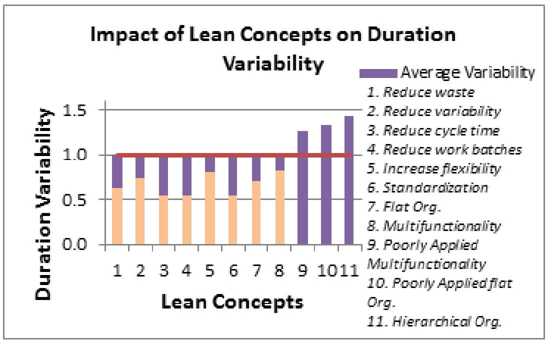

Figure 3: Variability Difference in Duration for each Lean concept scenario as compared to the base case calibrated for each Project.

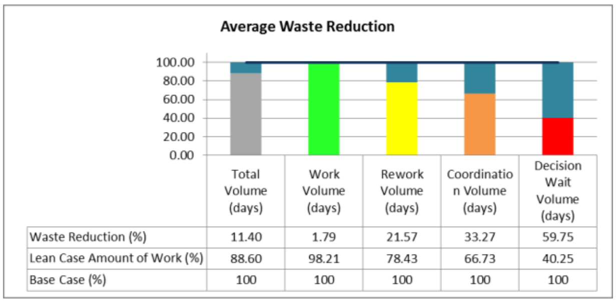

Figure 4: Reduction of process volume when applying the concept of waste reduction.

CONCLUSIONS

This research was able to model Lean Construction concepts through the VDT methodology. This not only achieve to show from another perspective the positive impacts of Lean on the projects results, but also offers a new methodology to include Lean principles in the design of organizations and projects processes. The calibration of VDT probabilities parameters adjusted to the reality of Chilean projects was effective. The values were within expectations and were validated by professional respondents. The only point to consider is that the Functional Error and the Project Error probabilities are a little low compared to the observed in the experience of the VDT expert modelers. This can occur because the returns that are handled in planning departments already include coordination work, so in the initial models, the net direct labor is increased, causing lower rework probabilities. This corresponds to one of the identified challenges to successful implementation of these models locally, which generally have to do with technical details such as improving planning and knowledge management, and insert into the strategy of organizations research promotion and development to improve the company and industry. With regard to the assessment of the impacts of Lean principles using the VDT methodology, a positive impact in all cases with the expected variations between projects was evident. On average, the principles caused greater impact on reducing the projects outputs were "Reduce Variability" and "Improving Flexibility", which shows the importance of generating a continuous flow and reduce uncertainty. The Lean principles that most reduced the time variability in the study projects were the principles "Reduce cycle times", "Standardize" and "Reduce work batches." This is consistent with the definition of these principles in theory. The concepts that had less impact are the principles "Increase flexibility" and "Flat organizations".

This research raises several lines of future work, such VDT calibrations depending on size/type of business, work areas, deadlines and other conditions, also, Lean organizational designs through VDT and its validation with real project results, and exploration of the VDT modeling with other Lean concepts.

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ANALYSIS OF DEFINITIONS AND QUANTIFICATION OF WASTE IN CONSTRUCTION

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ABSTRACT

Waste avoidance is an essential idea of the Lean philosophy, as this approach significantly contributes to maximize value from the customer's perspective. Waste occurs in diverse forms, depending on the types of industry and of working processes. Elimination or reduction of waste to a certain extent requires the ability to identify waste and to make it transparent to the parties, involved in the working process.

Based on a comprehensive literature review, existing fundamental and independently developed definitions of waste in Lean Management in general as well as in Lean Construction are presented and compared to each other. A systematic overview of waste definitions is developed. Within this context three specific characteristics are assigned to particular definitions. Furthermore, case studies and empirical studies from literature are presented, which focus on the identification and quantification of waste of time in the value chain of construction processes. Arguments, showing that different waste of time studies are not comparable, are brought forward.

KEYWORDS

Waste; lean construction; definition of waste; waste of work-time; theory

INTRODUCTION

Starting from the automobile industry, a new management approach evolved in the last century. Particularly Toyota had been involved in creating this new approach, which was called Lean Production in the following. The major objective of this approach is the maximization of product value for the customer. To achieve this goal, Ohno (2009) stated that waste should be eliminated in the production system. Womack and Jones (2013) picked up the idea of Lean Production and adapted it to a general management approach, called Lean Management. The principles and ideas of Lean Production and Lean Management were transferred to the construction industry. The term "Lean Construction" is used in this context. Here the focus is on value maximization for the customer and on the elimination of waste as well.

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Since there are various definitions of waste in literature, the question arises, how waste is understood by different authors. Waste in production is usually associated with non-value adding activities. Nevertheless, definitions differ, not only between industrial production (production under controllable conditions) and the construction industry (on-site production), but also within each industry. In this paper three specific and defining characteristics of waste will be introduced to examine several definitions:1) Object of contemplation; 2) Effort and 3)Value perspective

Comparing the definitions, waste – especially in the construction industry – is associated with an extra effort of time. Most empirical studies, which are conducted, aim on measuring waste of work-time in construction. Thus, the paper analyzes and presents work-time studies.

DEFINITIONS OF WASTE IN LITERATURE

RESEARCH METHOD

Based on a review of English and German literature, in total thirteen significant definitions of waste are analyzed – six definitions deriving from the industrial production and seven definitions deriving from the construction industry. This analysis focuses only on fundamental and independent definitions of waste. Thus, the main criteria for the selection of significant definitions are that more than one specific kind of waste is defined by the authors, e.g. corruption (Stifi, Gehbauer and Gentes, 2014).

In the following the definitions of waste within literature are presented and compared to each other (see Table 1). The definitions are analyzed with respect to the above mentioned characteristics. All aspects covert in specific studies are assigned with “x” (e.g. effort by Ohno, 1988). As some researches do not give a broad explanation on the characteristics, some other aspects of their definitions cannot be precisely assigned. Where applicable, an “o” is used (e.g. object by Polat, et al., 2004).

CHARACTERISTICS OF WASTE IN PRODUCTION

In literature waste in production is usually associated with an object of contemplation that does not provide any value and requires some kind of effort. Hence, there are three defining attributes that are characteristic for waste in production and construction.

Object of contemplation

The object of contemplation defines, what is related to waste. In general there are two approaches. Focusing on the processes, which is passed by product, in the first approach waste is related to activities. In the second approach waste is related to the product and therefore focuses on the outcome of production processes.

Effort

Regarding specifications made concerning the efforts linked with waste, there are two groups of definitions. Some definitions give accurate specifications, others only give a vague description of efforts they associate with waste.

Value perspective

Considering the entire production process, another essential feature of waste is linked with value loss. Basically there are two different approaches dealing with value in literature. On the one hand, researches describe value for the client. The client defines the value of a product in compliance with its ability to satisfy his needs and requirements. According to Bølviken, et al. (2014) value for the customer can be defined from the gross view and from the net view. Unlike the net view on value, the gross view does not consider the costs linked with the product. On the other hand, some authors describe value for the producing company. Here value is the efficient use of resources to reduce production costs.

FINDINGS

Using examples, four definitions of waste are analyzed in the following. Therefore, two definitions (the oldest and newest in the analyzed time period) from industrial production and two from the construction industry are chosen.

"In production waste refers to everything that only raises the costs, without adding any value [...]" (Ohno, 2009, pp. 91-92)

Ohno (2009) does not limit the object of contemplation. But he notes that his definition relates specifically to production. Ohno relates waste to *additional expense of costs*. Furthermore, he states that costs are incurred by *surplus stocks of workers, machine/equipment and products*. For Ohno (2009) value added is the transformation of product in its shape or function.

"[...] Muda refers to waste of unnecessary activities. This type of waste is characterized by using time, money and resources, while not adding any value to the customer." (Pieńkowski, 2014, p. 3)

Pieńkowski (2014) connects waste with *activities*, which are not necessary. Thus, an activity that adds no value is not waste, as long as it is necessary to perform a value adding activity. Further, an activity has to consume *resources* to be waste. In this case, the consumption of *money* and *time* is mentioned. Pieńkowski (2014) attributes explicitly the *customer* to his definition of waste. According to this definition the costumer decides, which activities will be classified as value added.

"Non-value adding activity (also called waste): Activity that takes time, resources or space but does not add value." (Koskela, 1992, p. 17)

As in other definitions, Koskela relates waste with *activities*. Effort is defined according to definitions in industrial production. A characteristic of waste is the effort of *resources*. Furthermore, two dimensions are introduced, which play an important role in construction projects: *time* and *space*. Koskela considers a missing value added as a major characteristic of waste. Only activities which transform material and information according to customer requirement extract maximum value.
"Waste is the use of more than needed, or an unwanted output." (Bølviken, et al., 2014, p. 813)

The definition of waste by Bølviken, et al. (2014) is based on the TFV-Model (see Koskela, 1992) of production and relates waste to unnecessary *activities* as well as to the *product*. In Bølviken, et al. (2014) the use of more than needed is the characteristic related to waste. This is about the use of resources during production. It is distinguished between the transformation aspect (involved resources: *equipment, energy and work*) and the flow aspect (involved resource: *time*). Thus, waste has the characteristic to consume more resources – equipment, energy, work und time – than necessary. Bølviken, et al. (2014) define value as the output requested by the *costumer*. The product value depends on the usability and functionality. It is pointed out that the definition is developed from the *gross perspective* and that the product costs are excluded.

Table 1: Definitions of waste

		object		**effort**									**value**		
Authors	year (first edition)	activity	product	energy	machine /equipment	material	money/cost	performance/labor	resources	rules	space	time	Client gross	Client net	company/product
industrial production															
Ohno	1988		x		x	x	x	x					o		
Womack and Jones	1996	x							x					x	
Górecki and Pautsch	2010	x			x			x			x			x	
Zollondz	2013	x					x		x				o		
Wagner and Lindner	2013	x							x					x	
Pieńkowski	2014	x					x		x			x	x		
construction industry															
Koskela	1992	x							x		x	x	o		
Formoso, Isatto and Hirota	1999	x			x	x	x	x					x		
Howell	1999		x									x	x		
Alwi, et al.	2002	x					x		x		x	x			x
Polat, et al.	2004	o							x	x			x		
Kalsaas, Formoso and Tzortzopoulos	2013	x							x			x			x
Bølviken, et al.	2014	x	x	x	x	x		x				x	x		

DISCUSSION OF THE RESULTS

Table 1 shows that waste is primarily associated with activities. Especially in industrial production all definitions of waste, except Ohno's, link waste to activities. Looking at the construction industry differing approaches can be found. Particularly the definition of waste by Bølviken, et al. (2014) is outstanding. Exclusively this definition of waste is built on the TFV-model of production. Hence, it is possible to distinguish between a transformation, flow and value perspective of waste.

Comparing the efforts that waste is associated with in the different industries, one finding is that the extra effort of time is stressed in the construction industry.

A general finding of the literature analysis is the different interpretation of waste: In particular this applies to the meaning of the term "resources". Some definitions only link resources to raw materials, whereas others also link resources with space, time etc.

EMPIRICAL STUDIES ABOUT WASTE OF WORK-TIME

RESEARCH METHOD

In the past several empirical studies were conducted, trying to quantify the amount of waste of work-time in construction. Since construction work is highly labour intensive, time is an important resource in construction.

Referring to the TFV-Model, Bølviken, et al. (2014) states that from the flow perspective waste is directly linked to time loss. Therefore, data collected in these studies are expected to provide a better understanding of possible improvements in flow activities in construction.

Starting with an analysis of IGLC papers and their references, the review of literature dealing with waste of work-time is extended to the main journals and conferences on construction management. After analyzing seven significant studies on waste of work-time, the research is stopped since there is sufficient data to show that the results of the studies vary too much to compare them to each other. Subsequently reasons for the noncomparability are discussed.

As there are several different categorizations of work activities, this paper aims to unitise the different studies. According to the categorization by Womack and Jones (2013), the basis for this homogeneous categorization of work activities is as follows:

- Value adding activities
- Non-value adding activities, but required (Muda 1)
- Non-value adding activities, not required (Muda 2)

Value adding activities are all activities that transform material towards the requirements of customer. Therefore, all non-value adding activities are defined as activities, which do not transform material towards the customer's requirements. The non-value adding activities are further differentiated in Muda 1 and Muda 2. There are non-value adding activities that are necessary (Muda 1), because they enable a following value adding activity. Muda 1 is necessary, because the following value adding activity could otherwise not be executed according the current state of technology. And there are non-value adding activities that are not necessary and can be prevented (Muda 2) (Womack and Jones, 2013).

Besides the empirical studies in waste of work-time in construction, there are also attempts to quantify waste of work-time in product design and material waste in construction. Measurements of waste of work-time in product design are often executed within a survey. The results of these surveys show that the respondents estimate the amount of waste representing about 30 % of the complete working capacity (Graebsch, Lindemann and Weiß, 2007). Here it has to be noted that these surveys do not surely focus on the product design phase in construction, but embrace a lot of different branches.

DIFFERENCES BETWEEN THE STUDIES

Table 2 summarizes the characteristics of each study. Besides the use of different categorizations of work activities, the studies also use different measurement methods. Furthermore, they measure waste of work-time in different countries and in different trades.

A lot of studies do not distinguish between trades, but give an overview of the measured waste of work-time. Other studies combine trades and thus the comparison of findings is impossible.

There are differences in applied methods of measurement. All analyzed studies use the observation method. The main difference between the methods is the extent of the measurement. Diekmann and Krewedl (2004) for example, record every activity change of workers, whereas Kalsaas, Formoso and Tzortzopoulos (2013) and Kalsaas, Walsh and Alves (2010) record activities in five minute intervals. Some studies do not provide detailed information on their methods.

Diekmann and Krewedl (2004) as well as Ramaswamy, et al. (2009) already use the homogeneous categorization of work activities. Differing categorizations can be seen between Josephson and Saukkoriipi (2005), Kalsaas, et al. (2014), Kalsaas, Formoso and Tzortzopoulos (2013) as well as Kalsaas, Walsh and Alves (2010). The defined “direct work” can be classified as value adding activity. The category “indirect work” can be linked to Muda 1, as it is necessary to enable further value adding activities. Moreover, the categories “material handling”, “work planning”, “planning, coordination and HSE (Health & Safety)”, “coordination”, “handling of materials”, “cleaning up”, “unloading and unpacking” and “rigging” can all be related to Muda 1. The remaining categories, which are not linked to any of the homogenous categorizations yet, are considered to be Muda 2. These are: “reworking”, “unutilised time”, “waiting and interruptions”, “other”, “necessary personal time”, “observable waste” and “inspections”.

DISCUSSION OF THE RESULTS

Figure 1 shows that the results of the different studies (waste of work-time) vary a lot. In the following possible reasons for these variances are discussed.

In general, the assumption can be made that a wide range of constraints exist in a study (e.g. equipment, technology, climate etc.). Only if one constraint is variable, the influence of this aspect on waste of work-time can be analyzed precisely. However the outcomes of studies are not comparable, if several constraints of the respective studies differ.

Hence, the analyzed studies in this paper are not comparable, because of the following two reasons: The underlying data of the studies is insufficient and the constraints differ significantly.

The studies are executed in different countries, by different observers. Furthermore, the studies are conducted in different projects with different trades. Thus, the hypothesis of this paper is that there are three decisive constraints. If these constraints are kept constant, it might be possible to compare certain construction processes and thus reveal room for improvement.

Table 2: Summary of empirical studies concerning waste of work-time in construction

	Study	Year	Country	Trade	Method of Measurement	Work categorization
A	**Diekmann and Krewedl**	2004	USA	structural steel erection	three cases, hand data collection, video data collection (every activity change recorded), 2 days	value adding, Muda 1, Muda 2
B	**Diekmann and Krewedl**	2004	USA	pipe spool installation	2 cases, hand data collection, video data collection (every activity change recorded), 2 days	value adding, Muda 1, Muda 2
C	**Josephson and Saukkoriipi**	2005	Sweden	different trades	observation	direct work, indirect work, material handling, work planning, reworking, unutilised time, waiting & interruptions, other
D	**Ramaswamy, et al.**	2009	India	different trades	6 cases, random work sampling, video analysis, 5-7 days	value adding, Muda 1, Muda 2
E	**Kalsaas, Walsh and Alves**	2010	Norway	electricians, plumbers, carpenters	observation (every 5 minutes), 11 days	direct work, personal time, coffee and lunch breaks, handling of material, cleaning up, reworking, rigging, unloading and unpacking, inspection
F	**Kalsaas, Formoso and Tzortzopoulos**	2013	Norway	pipe installation	observation (every 5 minutes), 2 weeks	direct work, indirect work, coordination, necessary personal time, observable waste
G	**Kalsaas, et al.**	2014	Norway	plumber, electrical, concrete, iron, carpenter, bricklayer	six cases, observation	direct work, observable waste, planning coordination and HSE, indirect work, logistics, indirect work, other, necessary personal time

Constraint 1: Observer and method of measurement

Comparing the findings of the studies, it should be considered that observers might interpret the work-related activities differently. Graebsch, Lindemann and Weiß (2007) found out in a survey that respondents with experience in lean management tend to estimate the portion of Muda 2 higher than those without. This can lead to a distortion of the results. Furthermore, different time intervals are used to register the changes in activities. Kalsaas, Walsh and Alves (2010) claim that the shorter the time intervals the better activities can be distinguished and the more waste emerges. This could be one of the reasons, why the amount of Muda 2 differs in the studies. Diekmann and Krewedl (2004) recorded every single change of activity, whereas Kalsaas, Formoso and Tzortzopoulos (2013) and Kalsaas, Walsh and Alves (2010). recorded the activities in five minute intervals.

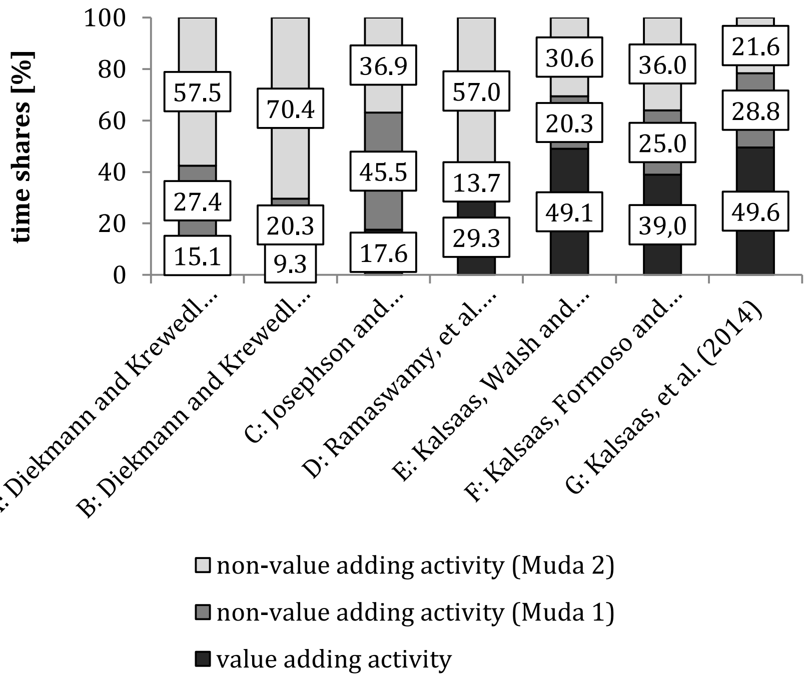

Figure 1: Overview of time measurement studies

Constraint 1: Observer and method of measurement

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Constraint 2: Characteristics of the projects and trades involved

Diekmann and Krewedl (2004) determined that the characteristics of a project have a big impact on the subdivision of the work-time. First of all, their study shows that light-gauge steel construction consists of less Muda 1 than heavy-gauge steel construction. Heavy-gauge steel constructions require the workers to pay extra attention on safely positioning elements into their final position. Thus they require more time than necessary non-value adding activities (Muda 1) than in light-weight steel construction projects.

There are also differences in the subdivision of work-time use between trades. Diekmann and Krewedl (2004) reveals that the pipe layers' or plumbers' work contains significantly more Muda 2 than the steel workers' work. The study of Kalsaas, et al. (2014) supports these findings. In the study it is found out that plumbers only use 31.5 % of their work-time with value adding activities, which is by far the lowest measured data value.

Constraint 3: Country

The country-specific ambient conditions could have an influence on measured waste of work-time. First of all, the developmental stage of the particular country might have an impact on the amount of waste of work-time. Especially the level of present infrastructure determines the possibilities to build lean (e.g. poor road systems affect supply).

Another country specific influence might be politics, providing the legal framework. The minimum wage for example affects the amount of construction workers a contractor can employ. On the one hand, the employment of more workers than necessary can speed up the construction process, but on the other hand, it can lead to mutual interferences and thus resulting in a higher amount of measured waste of work-time.

Furthermore, the climatic location of the country might be a reason for variances in the measured waste of work-time. Construction workers working in tropical climate for example, are expected to require additional breaks.

CONCLUSIONS

The research on the definitions of waste in literature shows that in both areas, industrial production and construction industry, primarily assign waste to activities. Nonetheless, these definitions reveal differences in the determination of value loss and in the effort connected to waste. Addressing the effort waste is associated with, time loss is emphasized in construction. Regarding value, the examined definitions differentiate between value for the customer and value for the company. However, most researches have an emphasis on the customer’s perspective.

Since the definitions of waste in construction focus on time loss a lot of empirical studies in construction focus on waste of work-time. Due to differing work categorizations used in these studies and the different conditions of the projects, they are hardly comparable. In this paper the different work categorizations were unitised. Based on this it is found out that the measured data varies intensely. The amount of Muda 2 for example ranges from 21.6 % to 70.4 %. Muda 1 varies between 13.7 % and 45.5 % and the value adding activities vary between 9.3 % and 49.6 %. Subsequently causes for deviations in the results are investigated. There are many different constraints that have an impact on the measured results. The three aspects observer and method of measurement, characteristics of the projects and trades involved and also country are identified as significant constraints.

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REASONS FOR AN OPTIMIZED CONSTRUCTION LOGISTICS

Sebastian Lange[1] and Dominic Schilling[2]

ABSTRACT

The claim of German builders is to realize individual and complex construction projects in the shortest possible design and construction time. Thereby the target achievement depends on a systematic and structured planning of the construction site and the associated construction sequences.

The construction logistics has the function to coordinate the core areas material, employees and information so that the correct material is available on a proper price, at the correct place, at the right time, in the exact quality and quantity, for the correct client (7 R's). Through the implementation of a superior, need-based coordination of the logistics, based on the required quantities, an efficient realization of buildings is feasible. Thus, time, quality and cost targets can be achieved.

Unclear is the question about the cost assumption for the site logistics. As for large-scale projects in Germany normally general contractors are assigned, they want to apportion the costs for the logistics to their subcontractors. Therefore, based on a practical example the trade-specific logistical effort is measured and characteristic values are generated. Based on these characteristic values the resulting logistical effort can be offset against the subcontractors. Through a lean logistics, also incentives for all parties are created.

KEYWORDS

Lean construction, logistics, value stream, work flow.

INTRODUCTION

Due to the ongoing individualization of products and additional industry-related challenges such as time and competitive pressures, lean production and business processes often become essential. This streamlining is also referred to as Lean Philosophy. However, the Lean-thoughts epitomize not only short-term single measures, but also a sustainable and long-term corporate philosophy. Recently, new combinations of notions such as Lean Production, Lean Thinking and Lean Logistics are gaining in importance and are summarized under the term Lean Management. Hence, Lean Management is an approach that transfers the Lean Philosophy to all business divisions and functions (Koskela, 1992).

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Whilst the subject Lean Construction is applied for many years successfully in the international construction industry, on German construction sites lean methods are used sporadically. The fundamental pursued objective is the optimization of the value streams. By using lean business processes, a continuous increase in power efficiency can be achieved. This efficiency is reflected in revised indicators such as cost, quality and delivery reliability and a higher process stability and reliability. Eying the building processes there is potential in the implementation phase especially in the field of the construction logistics (Kalsaas, et al., 2011).

In Germany, this can generally be attributed to the fact that each trade brings the required material or gets it delivered to the construction site based on their own planning. The consequences can be, among other things a late delivery of materials, delays in loading and unloading, unorganized storage and idle time due to a not terminated crane assignment This issue has been figures out almost 20 years ago by Bertelsen and Jorgen (1997), but nothing has changed in Germany until today. Instead, on German construction sites delays in the construction and thus interruptions in the value added chain are a daily occurrence. Leading to missed deadlines and rising costs.

The paper shows a way how on large construction sites in Germany, where often a general contractor with many subcontractors is used, the site logistics could work. A crucial role is played by a central managed site logistics, responsible for the implementation of the 7 R's of the logistics. How the occurring costs for the coordination and transportation can be allocated transparently and fair to the subcontractors is shown based on a practical example.

WASTE AND CONSTRUCTION LOGISTICS

WASTE

The guiding principle of Lean Management is the elimination of all types of waste. Waste (Muda) applies for all activities consuming resources without generating (additional) value of the product and consequently do not directly contribute to value creation (Womack and Jones, 2003). Ohno (1988) distinguishes seven types of "Muda":

- Transport
- Inventories
- Movement
- Waiting
- Inappropriate Processing
- Over-Production
- Defects

The value of a product is divided into material and service. In large part, the value added of a product is generated within the production. The value added is defined as the difference between the value of a product before and after its manufacture. In logistics, the product undergoes usually no further transformation, but is merely transported and stored. Hence, the logistics is in line with the service

(Mossman, 2007). For the customer the value in logistics increases if the 7 R's of the logistic are observed (Silva and Cardoso, 1999). Those provide that

- the right product,
- with the right quantity,
- by the right quality,
- at the right time,
- at the right place,
- to the right costs and
- for the right costumer are supplied.

CONSTRUCTION LOGISTICS

An exceptionally wide range of transported goods characterizes the construction industry. The building site, which includes accommodations, scaffolding and equipment, represents the construction logistical starting point. During the actual construction phase the transport of building materials and construction operating supplies predominates. However at the same time, the disposal and recycling of construction waste and work equipment is an important factor.

The construction logistics comprehends in addition to the planning and execution also the steering, documentation and the monitoring of all project related flows with regard to materials, persons, working medium and information. Mossman (2007, p.199) states that “good logistics is concerned with how people, information, equipment as well as materials arrive at the workface able to create value in safety and comfort“.

Figure 1 illustrates that the construction logistics can be divided into the sectors: procurement logistics, site logistics, disposal logistics and information logistics.

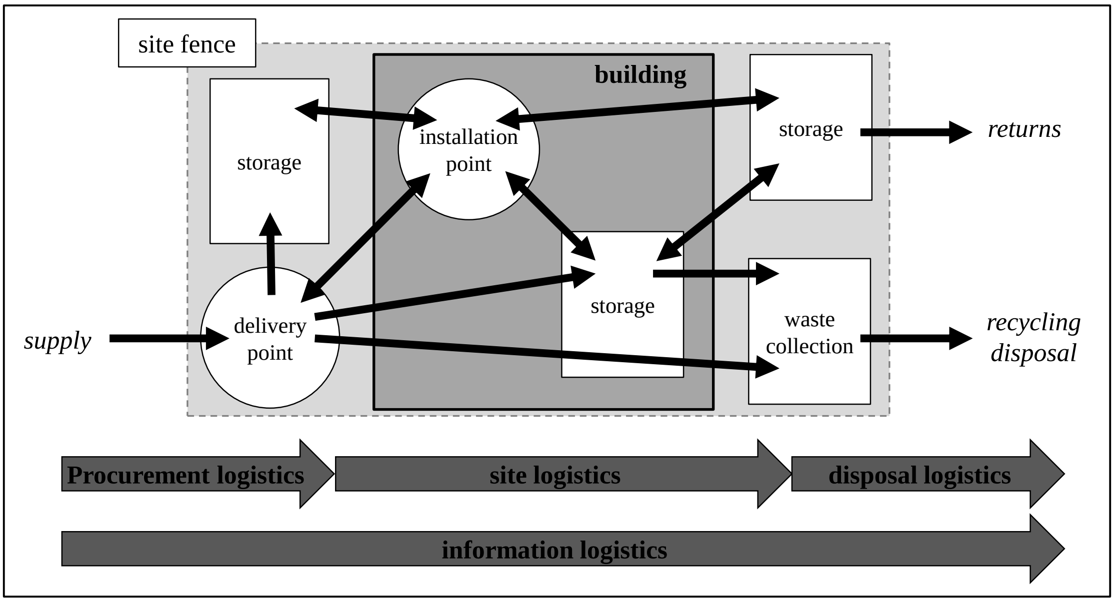

Figure 1: Sectors of the construction logistics (Figure 3 in Krauß, 2005)

The procurement logistics exclusively deals with the supply of goods and ends with the arrival of those goods on the construction site. As orientation guide for this purpose the construction border, which is normally the hoarding, can be used. Once the goods are on the site, all transportation and processes are assigned to the site logistics. This includes all transport-, handling- and storage-processes done with cranes, concrete pumps, lifts or forklifts until the objects arrive at their irrevocable installation point.

The differentiation between site logistics and disposal logistics can be done in a variety of ways. Depending on the view it is possible to have a separation already at the point of origin or not before the arrival of the waste at the collecting point on the construction site. In the context of disposal logistics, however, not only reutilization and removal processes of construction waste are considered. In addition to demolition waste, dredge spoil or packaging it covers also the removal of the site equipment.

The fourth sector is the information logistics. A coordinated, reliable and continuously flow of information is one of the main problems within the fragmented project handling (Girmscheid, 2010). Based on the logistical idea of a connection of information to other objects and consequently the impact on other transportation processes, the information logistics is classified as an important cross function. According to the current understanding of logistics the information logistics should not be limited to the objective flow of supply and waste removal but should cover a holistic view on the flows of information. Meaning also information flows from areas such as plan covering the project, scheduling, or building site are to be considered (Krauß, 2005).

PROBLEM AREAS AND TARGETS OF AN OPTIMIZED CONSTRUCTION LOGISTICS

PROBLEM AREAS

Arbulu and Ballard (2004, p.5) define that ‘‘variability is omnipresent in any production and supply system”. This finding illustrates a universal basic problem of the logistics. Therefore, a hundred percent reliable and smooth workflow is an utopian and unattainable notion of theory (Arbulu and Ballard, 2004). Within each production, the supply chain shows fundamental variances on the side of the provision as well as on the side of requirements. In the construction industry this subject is in particular distinct. As typical problems e.g. following issues can be mentioned:

- Missing or delayed deliveries.
- No direct unloading of transporters.
- Ineffective management of storage space.
- Installation of wrong and damaged material.
- No or insufficient separation of emerging waste.

The mentioned issues negatively affect in particular the productivity of a site (Elfving, Ballard and Talvitie, 2010). Numerous working hours studies yield that only a third of the total working time is used for the principal activity. Another thirty-three percent of the working time passes by for additional business and interruption that are essential and inevitable in providing the principal activity. To these belong recreation-related, workflow-related and individual-related interruptions. The remaining third of the working time is used for avoidable additional business and fault-related interruptions. All clean-up efforts and search processes as well as unnecessary covered distances and waiting time are reflected in this percentage. Only by using more than 50 percent of the working time for the principal activity a construction progress according to plan, without any serious loss of time, can be ensured (Berner, 1983). In order to increase the worker productivity of a construction site it is important to identify and eliminate the named weaknesses.

The illustrated shortfalls often have their seeds in the fundamental problem of an insufficient production planning. The successful realization of a construction project requires an accurate and extensive planning, which does not only include the set and project aims, but in particular the path to reach it. A construction-accompanying project planning often prohibits the planning of the path. Therefore, a consistent logistics understanding as well as an integrated overall logistic planning is extremely difficult to realize.

Furthermore, material flows are a coordinative challenge with high potential for optimization on large construction sites where different trades are working often in parallel.

Nevertheless, the production on the construction site depends on a variety of uncontrollable and unpredictable parameters. Weather, traffic accidents and strikes are only some examples for this purpose.

TARGETS OF AN OPTIMIZED CONSTRUCTION LOGISTICS

The guiding principle of an optimization of the construction logistics is to eliminate the exemplified problem areas. With the help of a logistics management efficient and effective logistic processes should be created. In the ideal case all non-value adding activities and accompanied costs are reduced to a minimum or can be even eliminated completely. This development conforms to the principle of the Lean Philosophy. The goal is to slim down all business processes within a company and to boost consequently the value added.

In order to achieve those objective targets, the construction logistics has to fulfil different tasks. They can be deviated with the help of the overall 7 R-rule. For the site logistics this means to provide the

- correct inventories, hand tools or materials,
- at the installation point,
- at the right time,
- in the right quantity,
- and in the right quality,
- for the right subcontractor
- as well as for the proper costs.

The realization requires a detailed planning of all supply and waste disposal processes as well as of all transport-, handling- and storage-processes.

Hence, a stage of construction and trade related coordination with regard to timing for the consumption rate and the necessary supply and waste disposal capacities is required. For this purpose all required consumption rates and quantity delivered as well as the exact point of time have to be registered in time for the respective stage of construction. Based on the registration the delivery time slot is checked. As test criteria among others, the capacity of storage and dumping grounds as well as the capacity of lifts and cranes are consulted. Nowadays, registration, checking and approval are usually done via digital coordination platforms. The illustrated factors can be summarized in some overall and transferable principles for the construction logistics (Girmscheid, 2011):

- Early registration and coordination of deliveries.
- Prevent inefficiency because of parallel work at one place.
- Plan transportation routes and storage rooms for each construction phase and stage of construction.
- Avoidance of material rearrangement.
- Order and cleanliness at the construction site.
- Protection of stored materials and worked construction performances against any kind of damage.
- Keep trails free for supply and waste disposal purposes.
- Minimization of storage room by better coordination of storage and Just in Time deliveries.
- etc.

CHANCE FOR THE OPTIMIZATION OF THE SITE LOGISTICS IN GERMANY

The production planning provides the basis for an accurate planning and provision of trade-specific required materials. As the planning often occurs simultaneously to the construction progress such a foundation is a general problem in Germany and Just-in-Time deliveries are made almost impossible. Aggravating this situation, the different subcontractors are having their own planning on the basis of which they deliver their materials to the construction site. These aspects are reflected in an unorganized storage. An opportunity to still reach a continuous flow of materials according to the lean principles is a centralized logistic management, which verifies, coordinates and carries out all site logistics material and information flows.

The activities of the logistician can be separated into different super ordinate main sections. Thus, his fields of activities are the already named procurement, site and disposal logistics. Furthermore all these aspects are accompanied with an automatic information logistics. The pursued objective is to create optimized working conditions for all parties involved. Due to the timely planning and coordination of all transports, a smooth and continuous construction process without any uncoordinated deliveries or temporary storages is ensured. Also the existing building site equipment isn’t overextended. Another advantage is that downstream trades are able to focus on their principal activities.

Besides these positive effects it is necessary to consider, that large-scale projects in Germany are normally implemented by general contractors, who are primarily in charge of the additional costs for the engaged logistician. Hence, they strive to pass on all these costs to the different subcontractors. In Germany the cost allocation is usually calculated with a fixed rate of 2 - 3% on the subcontractor’s contract value.

Since there are no evidences or reference values with regard to the trade-specific logistic efforts so far, it is necessary to determine such specific values. On the basis of these values the costs incurred can be allocated transparently to the subcontractors and additional incentives for a needs-based logistics are provided.

The system of such a construction logistics concept will be demonstrated in the following practical example. Specific values will be generated to determine and allocate the trade-specific logistic costs properly.

The practical example is a new office building in Germany with a total cubical content of about 220.000 cbm and a gross floor area of nearly 50.000 sqm. Due to these figures the example can be categorised as a large-scale project. The construction proves is implemented by a general contractor who is applying lean construction methods. The agreed allocation for logistic costs is 2 % of each contract value. This amount includes the time as well as the machines that are required.

For the generation of the trade-specific characteristic values the logistics company was attended on several material handlings. The focus of the investigation was on deliveries from the supplier's central store to the point of installation. Three trades with high logistical effort caused by the weight or dimensions of the materials were analyzed:

- Cavity floor
- Plasterboard
- System partition walls

During the data collection it appeared that the used number of cranes, goods lifts, lorries, etc. was for all trades comparable. Therefore this aspect was no longer taken into consideration. According to this the specific values are based on the number of deployed workers, the individual scope of delivery, as well as the time scope. In fact of differing numbers of deployed workers and time scopes the accompanied delivery procedure was separated into the two processes 'unloading' and 'move'.

As presented in Table 1, the generated specific values (column 3) seem very short. But if the scope of work (column 4) is taken into consideration the supposed short time periods are summed up to huge amounts. For example the 28.000 sqm of cavity floor are causing a logistics effort of almost 400 h (column 6). This logistics effort and the average hourly rate of 40 €/h result in trade-specific logistics costs of 15.916,99 € (column 8). The hourly rate of 40 € contains the use of a forklift operator, including the machine, as well as other workers, who are engaged to move the material. By means of the total logistics costs (column 8) it is clearly evident, that the accruing logistic arrangements are causing a huge and significant time and cost factor, even if the determined figures seem very short in the beginning. Furthermore Table 1 shows that the application of a fixed rate for the cost allocation (column 10) does not reflect the reality. Therefore appropriate and individual cost allocations have been determined (column 11). Against all expectations the costs for material handlings of the trades 'cavity floor' and 'plasterboard' are below 2 %. In contrast the agreed cost allocation for the trade 'system partition walls' is too low (column 12).

Table 1: Trade-specific characteristic values from general contractor's side of view

1	2	3	4	5	6
trade	**specific values**		**scope of work**	**logistics effort**	
	process[h/sqm]		**[sqm]**	**[hh:mm:ss]**	**[h]**
cavity floor	unloading	00:00:05	28.000,00	41:31:18	41,52
	move	00:00:46		356:24:10	356,40
	∑	00:00:51		397:55:29	397,92
plaster board	unloading	00:00:03	20.000,00	16:57:44	16,96
	move	00:00:33		184:24:11	184,40
	∑	00:00:36		201:21:55	201,37
system partition walls	unloading	00:00:32	5.000,00	44:38:43	44,65
	move	00:07:10		596:41:22	596,69
	∑	00:07:42		641:20:05	641,33

	7	8	9	10	11	12
	logistics costs	**total logistics costs**	**contract value**	**agreed cost alloc.**	**actual cost alloc.**	**Δ cost alloc.**
	[€/h]	**[€]**	**[€]**	**[%]**	**[%]**	**[%]**
cavity floor	40	15.917	960.000	2,00%	1,66%	0,34%
plaster board	40	8.055	790.000	2,00%	1,02%	0,98%
system partition walls	40	25.653	795.000	2,00%	3,23%	-1,23%

The generated characteristic values can be used as an indication for the allocation of the logistics costs. However it is important to note that the logistical effort depends on the project type and that the characteristic values are transferable only in some degree. Moreover it is important to take the other sections of procurement and disposal logistics into consideration and to analyse how far they contribute to the total logistics effort of the different trades.

CONCLUSION

The construction logistics plays a key function during the project realization phase. It coordinates the core areas material, staff and information so that the value chain for the construction of the building is not interrupted. Basis for smooth processes is a final production planning. Therefore, especially in Germany clients need to be sensitized with regard to this topic. Even if the assumption of a smooth building process is utopian in reality, the optimization of the site logistics can have a substantial impact on:

- Reduction of inventories on the site.
- Delivery of materials in time.
- Consistent workload of the cranes, goods lifts, etc.
- Avoidance of material search.
- Focus on principal activities.
- Higher workflow and thereby free capacity.
- Clear responsibilities and transparent execution of construction work.
- Clean and safe site.

Especially deliveries for trades with a high logistical effort can increase logistic costs enormously during the project realization. This is the case if there is no logistics company doing a centralized logistics but rather the subcontractor is responsible for the transportation, supply and disposal of the material. Nevertheless, also a decentralized logistics can be "lean", if the production planning is completed at an early stage and if it can be implemented in the logistics processes. In addition, all in the construction project involved companies should act according to the Lean principles. As this is in Germany currently rarely the case especially on large construction sites, the construction companies are forced by the client to implement Lean measures. Therefore, incentives to increase the acceptance have to be created. One possibility has been demonstrated on the basis of a practical example, where the costs allocated to the subcontractors have been broken up transparently. Another positive aspect is that the characteristic values can give information and starting points for further lean measures in the construction logistics.

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A LEAN APPROACH TO MANAGE PRODUCTION AND ENVIRONMENTAL PERFORMANCE OF EARTHWORK OPERATION

Sheila Belayutham[1], and Vicente A. González[2]

ABSTRACT

Earthworks comprise of only a small number of activities, equipment and personnel but relatively large percentage of the total construction cost. Uncontrolled earthworks could increase risk to the environment, especially water pollution. Both production (time, cost and quality) and environmental measures are critical during earthworks and should be managed and improved holistically. Past researches have established the applicability of lean to improve the performance of production and environment in construction. However, limited results were shown for earthwork operations. Most lean based studies on earthworks focused on production planning and increasing productivity of the operation, neglecting the environmental emissions, particularly water pollution. Therefore, this paper aims to simultaneously improve the production and environmental performance (water pollution) of earthwork operations through the application of lean production. Thus, lean tools were used to recognize current production and environmental inefficiencies within an earthwork operation. Then, improvement strategies will be proposed in combination with common construction management practices such as site layout management and time planning to reduce and eliminate waste. The research findings could potentially provide direct production and environmental benefits to the construction industry as well as a safe and conducive setting to the public during construction.

KEYWORDS

Earthwork, production, environmental sustainability, lean construction, water pollution.

INTRODUCTION

Earthwork operation involves mass clearance and movements of earth around and outside construction site. This operation is critical as the resulting performance of this preliminary process may 'make or break' the following processes (Fu, 2013). Production (time, cost, quality) performance has commonly been the measure of

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success for this operation, over the environment (Lewis and Hajji, 2012). The imbalanced treatments of both criteria tend to push contractors to address one more than the other (Taylor and Field, 2007). However, the relation between production and environment could be closer than perceived. Earthwork operation involves the stripping of land cover that induces damaging processes e.g., excessive runoff, erosion and sediment, that increases the risk of water pollution. Apart from topography and geographical aspects, production factors such as time could also determine the severity of the damaging processes (Brown and Caraco, 1997). The common end-of-pipe system (silt trap, sediment pond) could only mitigate the resulting damages and do not prevent the occurrence in the first place. Allegedly, prevention strategies such as construction phasing are a better option in comparison to the mitigation approach (Brown and Caraco, 1997). The prevention strategies do involve strategizing the production factors, especially time, to minimize processes of excessive runoff, erosion and sediment production. In order to improve the production factors, lean production has progressively being used to enhance productivity in many areas including earthwork operation (Fidler and Betts, 2008). However, the vague link between production and environment has caused lean efforts to undermine the inclusion of the environmental dimension, which includes water pollution. Therefore, this research aims to simultaneously improve the production and environmental performance (water pollution) of earthwork operations through the application of lean production.

LITERATURE REVIEW

Earthwork has been plagued with productivity issues, consequently igniting interest among researches who are seeking to improve this construction operation (Martinez, 1998; Dawood, et al., 2010). Earthwork's progression is crucial in the development of a project because it determines, to a large extent, the proper flow of work for the following activities (Fu, 2013) that affects the time factor in a project. Furthermore, the requirements for expensive heavy equipment and skilled manpower involve major cost in a project. Earthwork has an influential effect on the overall success of a construction project but the uncertain and highly variable environment makes the success hard to achieve (Kirchbach, Bregenhorn, and Gehbauer, 2012). Various factors could affect the performance of an earthwork operation e.g., types of soil, haul road, site access point, location of borrow pit, construction method and equipment availability (Martinez, 1998). In addition to that, weather, operator's experience, haul distance and gradient, schedule restriction and conflict with other activities/ obstructions could also dampen an operation's performance (Christian and Xie, 1996; Martinez, 1998).

Earthwork only occupies short time period of a whole construction but the potential risk and threat to the environment is great through large scale of clearing and grubbing operations (Taylor and Field, 2007; Ooshaksaraie, et al., 2009). A calculated Universal Soil Loss Equation (USLE) figure for a cleared earthwork site reveals an estimated 16.14 tons of sediment production, in comparison to the pre-earthwork yield of 3.20 tons (Pain, 2014). If a cleared site is left uncontrolled and mismanaged, severe soil erosion and sediment production could take place, leading to water pollution (Ooshaksaraie, et al., 2009). Mass grading creates two critical variables i.e., time and size of area exposed, that should be well managed to minimize the negative effects of site clearance (Brown and Caraco, 1997; Pain, 2014).

Commonly, the environmental problems arising from earthwork operation has been treated in isolation from production (Lewis and Hajji, 2012). The independent treatment creates segregated efforts that may trigger the notion of one more important than the other. Hence, to mitigate this situation, mutual benefits by integrating production and environment should be demonstrated. Works have been done to integrate both the elements of production and environment in earthwork. Lewis and Hajji (2012) and Golzarpoor, et al. (2013) have provided a synergistic approach that combines production and environmental factors to determine the cost, fuel, energy and emission from earthwork operations. Gonzalez and Echaveguren (2012) and Capony, et al. (2012) also conducted similar research using discrete event simulation and GPS technology respectively. However, most of the studies concentrated on the issue of air and carbon emission with least regards for water pollution. Therefore, this research attempts to fill the knowledge gap by managing environmental issue of earthwork, from the standpoint of water pollution that also benefits the production.

LEAN EARTHWORK

In the area of earthwork, most lean approaches have been utilized to improve work production, whereby the approaches could be categorized under pure lean and technologically infused lean approach. For pure lean approach, Fidler and Betts (2008) and Kaiser and Zikas (2009) have used lean tools and principles to stabilize and improve the efficiency of the earthwork movements, increase equipment utilization, reduce cost and optimize labor resources. For improvements done with the help of the technological system, Dawood, et al. (2010) produced an interactive visual lean system for earthwork operations planning to achieve transparency, reduce complexity, waste and project time. Similarly, Kemppainen, et al. (2004) used two optimization algorithms to find the most cost-efficient schedule and mass haul alternatives that ultimately increased the functions of Last Planner system in Finland's construction industry. Kirchbach, et al. (2014) presented 'digital kanban', a system supported by machine sensory and IT that embraces the lean principles for an optimized earthwork productivity. Most studies applied lean to improve earthworks' production with little effort found to enhance the environmental variable.

LEAN AND ENVIRONMENT

Lean philosophy and environmental sustainability are two different concepts, conceived to address different goals. Pioneered in the manufacturing sector, lean approach has been widely credited for its potential to improve the production aspect of the industry. On the other hand, environmental sustainability is focused on reducing environmental impacts such as energy usage and greenhouse gas emission amongst others (Miller, et al., 2010). Despite the differences, Carneiro, et al. (2012) and Belayutham and Gonzalez (2013) suggested for both philosophies to be used complementarily. This is supported by benefits shown from growing amount of works on the integration of lean and environment in various sectors. Bergmiller and McWright (2009) found that manufacturing plants that implement lean in their production system tend to be greener than other common manufacturing plants. For a home manufacturing plant, the utilization of lean tools have increased process efficiency and reduced material wastage (Nahmens, 2009). Lean philosophy has also simultaneously improved the production and carbon efficiency in a precast concrete production (Wu and Low, 2012). In construction, Huovila and Koskela (1998) proposed to combine lean construction with sustainability objectives to eliminate material waste, minimize resource depletion and pollution.

RESEARCH METHODOLOGY

This paper displays a combination of theory and practical aspects of lean approach to enhance the production and environmental performance of an earthwork operation. Descriptions on the research methods employed to define the different aspects of Lean Earthwork Framework is shown in Table 1.

Table 1: Research Methods

Lean Earthwork Framework Aspects	Research Method	Details of Research Method
Step 1: Value	Literature Review	Literature review: Journal, conference, books, electronic articles, thesis.
Step 2: Value Stream	Literature Review Document analysis Observation Interviews	Observation: One earthwork site, one month duration.
Step 3: Flow	Interview Observation Document analysis	Interviews: Four earthwork contractors with an average of 15 years working experience.
Step 4: Pull	Interview Observation	Document analysis: Daily site diary.
Step 5: Continuous Improvement	Interview	

LEAN EARTHWORK FRAMEWORK

This framework will encompass the application of the five principles (value, value stream, flow, pull and continuous improvement) of lean thinking by Womack, et al. (1990) to enhance the earthwork operation. Using earthwork as an example, this framework could potentially be adapted to improve other operations, in line with the vast applicability of lean across different industries and sectors (Huovila and Koskela, 1998; Bergmiller and McWright, 2009; Nahmens, 2009; Wu and Low, 2012).

STEP 1: VALUE

Lean tools: SIPOC and 5 Whys

In an earthwork operation, the production and environmental variables have been dealt in isolation without considering the overall view on how it could relate, complement and impact each other. Therefore, to improve both variables simultaneously, point of similarities should first be established by deciding the value of the operation. For earthwork, the value from production and environmental perspective (water pollution) can be distinguished by identifying customers' voice using the SIPOC (Supplier-Input-Process-Output-Customer) tool, as shown in Figure 1. In general, customer is the recipient of the output from a process. Two outputs are involved e.g., production and environmental output, that needs to satisfy a set of different customers and requirements.

Supplier	Input	Process		Output	Customer	Requirements
• Earthwork Contractor	• Equipment • Skilled workers	Earthwork Operation Cut → Haul → Fill	PRODUCTION	• Graded earth • RL Platform	• Client • Next contractor	• Timely delivery • Within budget • Accepted quality
• Design engineer	• Earthwork plan • Erosion & Sediment Control plan		ENVIRONMENT	Land surface transformation • Excessive runoff • Erosion and sediment	• Receiving environment and its surroundings	• Clean water • Reduced emission to water body

Figure 1: SIPOC for Earthwork Operation

From Figure 1, there are no clear similarities shown between the customers' requirements (value) for production and environment (water pollution). Hence, a further derivation is required to find the point of similarity. To do so, a lean technique called 5 whys was used to derive potential factors that could affect the achievement of the value. 5 whys is a lean technique used to identify the root cause of a problem. The question why a problem exists is being asked and the answer is written below the aforementioned problem and the procedure will be repeated five times. The derivation could potentially provide a point of similarity, consequently providing one common value to be considered for both the production and environment (water pollution).

The derivation of the 5 whys for both variables have been conducted with the support of literature, shown in Figure 2. The factors derived for water pollution were taken from literatures (Shaver, et al., 2007; Kaufman, 2000; Brown and Caraco, 1997). Similar method was applied to identify the factors for earthwork production inefficiencies (Christian and Xie, 1996; Martinez, 1998). From Figure 2, time is identified as the point of similarity since both aspects of production and environment are affected by time. Time shortening of the earthwork operation could eliminate time overruns as well as reducing the number of rainfall incidents, consequently minimizing the risk of water pollution. Throughput time is recognized as the most utilized measurement factor to understand movement in processes (Koskela, 1992).

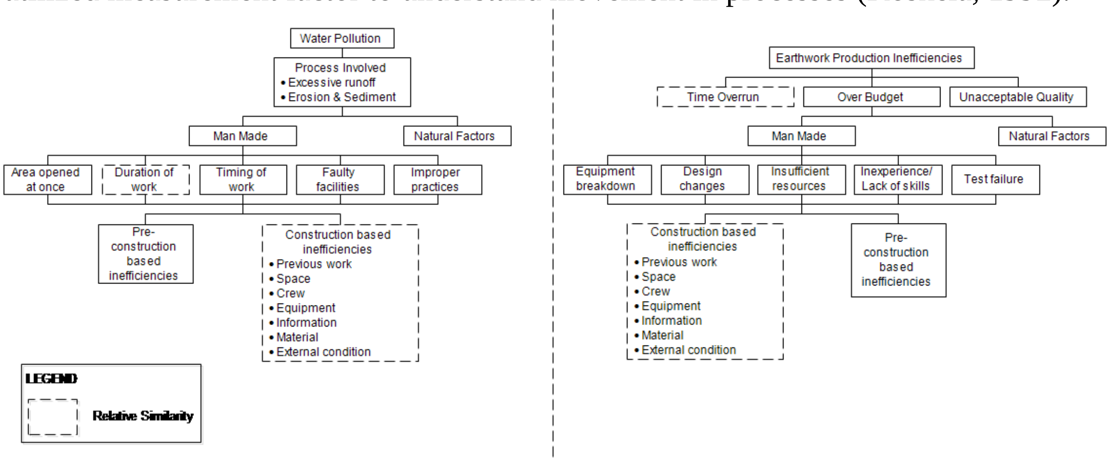

Figure 2: Point of similarity between earthwork production and environment

This step has provided a theoretical integration of value (time) to simultaneously improve the production and environment (water pollution) variables in an earthwork operation. For the purpose of this paper, it is presumed that the following lean steps to improve the time factor will benefit both the production and environment (water pollution).

STEP 2: VALUE STREAM

Lean tool: Gemba, Value Stream Map (VSM)

VSM was used to portray the current processes involved in the earthwork operation and comprised of three main processes which are cut, haul and fill. The main processes involved in an earthwork operation were earlier defined by Martinez (1998). In order to further derive the performance metrics of the operation, productivity scale for the operation should first be understood. Earthwork productivity could be measured with volume of earth per unit of time (m^3/t). Therefore, the flowing unit in this operation is m^3 of earth. In order to portray the details of earthwork in a VSM, data for the required indicators are shown in Table 2 (NZQA, 2015):

Table 2: Measured Indicators

Indicators	Measurement	Indicators	Measurement	Indicators	Measurement
Start day	Month/ day	Finish time	Hour/ mins.	No. of workers	No.
Finish day	Month/ day	Non-working days	Day	No. of trips	No.
Start time	Hour/ mins.	Distance travelled	m	No. of equipment	No.

From the indicators, production factors e.g., lead and cycle time, haul and return time, average haul distance, idle time, productive time, break time and output per day can be calculated. Current VSM based on the aforementioned processes and indicators is shown in Figure 3. The map details the progression of processes involved in one cycle of operation. After discussion with the site engineer, it is agreed that a single cycle of work would best be represented by 10 unloads to portray the earth movement with its related equipment. Therefore, 1 cycle = 10 unloads of earth.

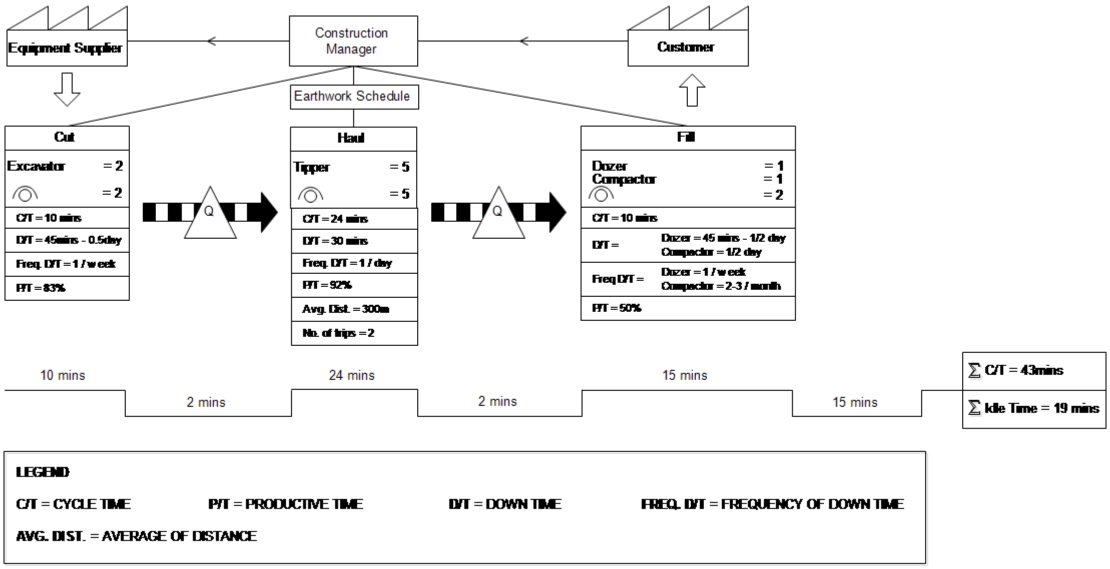

Figure 3: Current Map for Earthwork Operation

In this VSM, the use of lead and cycle time is aligned with the definition by Hopp and Spearman (2008) whereby, lead time is the maximum allowable cycle time for a job whilst cycle time is the average time for a job to go through a line. The reduction in lead time will shorten the period of operation, consequently reducing the risk for water pollution inducing processes i.e., excessive runoff, erosion and sedimentation due to rainfall.

STEP 3: FLOW

Lean tools: Root cause analysis

Figure 3 illustrates the process flow that shows VA (cycle) and NVA (idle) times when earth was not being worked on. The percentage of NVA (idle) time is 30.6% of the total lead time of 62 minutes. A large portion of the idle time (15 minutes) was found at the fill area where the dumped soil was not being worked on till it reaches 10 unload. Even though the idle time did not cause congestion to other work sections, the two idling machineries (dozer and compactor) represent waste in resources. A smaller portion of the total idle time can be seen at the cut area with 2 minutes idle time as the excavator waits for the tipper. In serving 5 tippers for a return haul trip of 12 minutes/ tipper, the excavator will have 2 minutes of idle time. Even though the figure seems small, cumulatively it could reach up to 40 minutes per day with a total loss of 280 m^3 soil.

Besides the obvious idle time waste, cycle time may also disguise some major flaw within the site practices, causing cycle time to be longer than necessary. An ideal cycle time is usually provided by the manufacturer but could vary due to different factors mentioned by Martinez (1998). Interviews were conducted among site personnel. From the interview, major contributing factors are given below, positioned from highest to lowest frequencies:

Frequent --> *Occasionally*

Machine breakdown; Weather (rain); Underground services

In addition, respondents were also asked about practice related factors that could affect the earthwork cycle time and productivity. The factors are given as follows:

- Skill and experience of the equipment operator is really important where the difference between experienced and less experienced ones could result in shortages of approximately 20 m^3 /day or 3 trips of tipper.
- At the cut section, the position and turning point/ swivel degree of the excavator creates differences in time and efficiency. Smaller swivel point is much efficient than large swivel points.
- At the fill section, cycle time increases when tipper unload soil far from the dozer. Common improper practices can also be found with compactors where vibrators were not activated in attempt to reduce cost. Non-vibrated compactor could cause a longer cycle time besides further damages such as failed compaction test that leads to unnecessary halt of the operation.

Hence, various reasons could be traced back in attempt to identify the root cause including some of the factors proposed by Koskela (1992), e.g., crew, equipment, information, external condition and previous work.

STEP 4: PULL

Lean tool: Just in Time (JIT)

The current processes (Fig. 3) are linked to each other using the traditional push system. Earth will be loaded by excavator into the tipper, which then will pass it on to the fill section. The push system created an overloading on tippers as there were insufficient tippers to satisfy the excavator's supply, consequently creating waiting period for the excavator. Mismatch happens when push is being applied without matching the availability of tipper, resulting in 2 minutes idle time per cycle for the excavator. The JIT technique allows contractors to critically plan their equipment usage, productivity and distance travelled in order to smooth the work flow.

STEP 5: CONTINUOUS IMPROVEMENT

Lean tool: Future map VSM, Kaizen

For this paper, the future map will not be drawn but suggestions for improvement are provided to increase the productivity of the operation, consequently resulting in shorter time and reduced risk of water pollution. In order to improve the current processes, the ill practices identified during the observation and interview should be eliminated (Refer Step 3: Flow).

For future improvements, earthwork planning should be done in conjunction with construction planning elements e.g., site layout, schedule and method. Proper site layout planning could enable the shortest haulage distance between process locations. Integration with construction schedule allows work sequences that do not necessitate the clearance of site at one go. This technique of construction phasing also promotes the preventive measures of water pollution as land will only be cleared when it is ready to be worked on. This could potentially be one of the strategies to manage the idle time found at the fill section. Schedule could be strategized for the fill section to be worked only once a day. Meanwhile, the dozer could be used to clear areas bit by bit, without the common whole site clearance. This strategy could eliminate the prior site clearance time (3 months for the site studied) as well as eliminating the idle time. This strategy provides mutual benefits for production and the environment (water pollution) since land will not be left open for long due to shorter operation period.

CONCLUSION

In an earthwork operation, the production variables (time, cost, quality) has often been the emphasis without realizing the potential harm the environmental aspect could have on production, if the latter is not being managed well. This research has illustrated the application of lean to simultaneously improve the production and environmental (water pollution) variables in an earthwork operation. A theoretical framework was drawn at Step 1 (value) to show essential link between both variables that could encourage contractors in working towards similar goal. The practical demonstration of certain lean tools at Step 2 (value stream) and Step 3 (flow) enables construction team to identify deficiencies in current workflow that affects the production rate and risk towards water pollution. The solutions proposed at Step 4 (pull) and Step 5 (continuous improvement) when being integrated with construction planning elements at initial work stages could produce a production and environmental friendly construction plan. Academically, the framework has filled the knowledge gap to integrate lean with the environment (water pollution), which was previously absent. A longer duration of study could provide a more comprehensive picture on the productivity of the operation. Future research will well benefit the construction industry when parts of this research are integrated with IT systems such as Building Information Modelling (BIM). BIM features such as what-if scenarios allow the generation of an optimal construction plan in terms of space, resource and time availability that benefits both production and environment (water pollution).

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PERFORMANCE EVALUATION OF LEAN CONSTRUCTION PROJECTS BASED ON BALANCED SCORECARD

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ABSTRACT

The development of lean construction theory and tools promote their applications in various countries. Scholars have used case analysis and empirical research to prove the function of lean construction in waste-reduction and value-added. However, performance evaluation of lean construction project still does not have a standard or systematic measurement, and this results in less recognition of its value and more barriers of its applications in many countries. Therefore, the aim of this study is to build an effective scale for its performance evaluation and measure the success of implementing lean construction in different kinds of projects.

This paper used balanced scorecard approach (not only financially and non-financially, but also on long-term and short-term account) to evaluate the performance of 300 construction projects which had adopted lean construction theory in China. It established evaluation index system from five dimensions and determined the weight of indicator of index system by factor analysis. Furthermore, we calculated the score of these individual projects, the results showed that index system was effective, and most of the projects with higher scores were municipal projects, constructed by state-owned enterprises or large private enterprises, which reflects good foundation of collaboration.

KEYWORDS

Lean construction, value, performance evaluation, balanced scorecard, collaboration.

INTRODUCTION

Lean construction is an application of using lean production to construction project management (Koskela, 1992), and the aim of its application is mainly to reduce waste and to improve performance of construction projects. Many scholars have used case analysis and empirical research to prove its role in the aspects of waste-reduction and

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value-added in many countries, such as Denmark (Bertelsen, 2001; Thomassen, et al., 2003), Indonesia and Australia (Alwi, Hampson and Mohamed, 2002), Chile (Alarcón, et al., 2005), America (Salem, et al., 2005). However, there are various problems in the implementation of lean construction in different states and countries. Alarcón, et al. (2005) assessed the implementation of lean construction in 100 construction projects for 5 years in Chile, and found that the problem of improving PPC value was the lack of the time to implement new technologies, training, self-criticism and to adapt to the changes. Daeyoung and Park (2006) interviewed 42 projects participants, and found that they were not familiar with the concept of lean construction, and there were many difficulties in the implementation of lean construction, such as the preparation, labor force, materials transfer and the precision in planning. Henry (2009) analyzed the construction industry in Uganda, and pointed out that the main hinder factor in lean construction implementation was the accurate supply on time. Salem, et al. (2006) pointed out that many lean construction tools and elements were still in embryonic state. He assessed the values of different lean construction instruments (such as last planner, increased visualization, five S's, et al.) for a general contractor in Ohio, and built a lean assessment tool called spider-web diagram. The researches proved the function of the assessment tool in tracking improvements in lean construction projects.

The lack of assessment tool of lean construction implementation results in less recognition of its value and barriers of applications in many companies. Therefore, the objective of this paper is to build an effective scale for performance evaluation and measure the success of implementing lean construction in different kinds of projects. The balanced scorecard model (BSC) (Kagioglou, Cooper and Aouad, 2001) not only emphasizes the financial and non-financial target balance, but also stresses the balance between short-term benefits and long-term benefits. Based on the particularity of construction project, its performance are not only reflected in the profits of funding, but, in some circumstances, non-financial goals, such as lean construction project quality and schedule, are more significant and become the focus of the performance evaluation. With the balanced scorecard, financial, internal staff's learning and growth, construction project strategic investment, and internal knowledge capacity combined, we can balance the current performance and the long-term performance of enterprises. In view of this, this paper tries to introduce the balanced scorecard theory model to the performance evaluation of lean construction project, and find the rule of the success of implementing lean construction in different kinds of projects.

METHODOLOGY

The research design was exploratory and based on theory analysis and quantitative analysis. First of all, the paper adopted the balanced scorecard (BSC) theory to establish preliminary evaluation index. BSC is a strategic performance measurement system originally, and has been widely received as one of most influential management ideas (Coe and Letza, 2014). BSC considers financial, internal business processes, learning and growth, and customer, these four perspectives, as interrelated and interacted. The internal system of learning and growth determines the quality of the staff, the staff in a certain extent determines the quality of their products, which determines customer satisfaction and loyalty, and all of these determine enterprises' market share and financial position. The coherence of intangible assets between these four dimensions makes internal processes more efficient, thus eventually achieve client objectives.

In order to verify the feasibility and reasonability of BSC evaluation index, the paper made a quantitative analysis by factor analysis, which is a statistical method that can reduce the dimensions of a set of highly correlated data but remain most of the information from the original variables (Thomson, 1935; Barth, 2008). Because of the high correlation among the four dimensions of BSC, factor analysis performs effectively as an evaluation method.

The performance of lean construction project is the effects or outcomes of the implementation of lean construction instruments such as 5S management, Last Planner System, Concurrent Construction, Visual Management, Just-in-time, Total Quality Management (TQM) and Conference Management. The performance of different projects would be different because of their distinctive management ability and culture, and we have investigated 300 projects in 61 cities of China and delivered 770 questionnaires to the first-line managers. The questionnaire contains two parts, the first part is basic information of the project such as the type of the project owner and its size, and the second part is about the project performance, the questions are designed based on BSC evaluation index, and contains 18 questions, which elaborates the following parts. The items adopt 5-Likert Scale scoring 1 to 5 while “strongly disagree” to “strongly agree”. The questionnaires are recovered 710 totally and there are 667 valid after screened out. The types of projects contain civil construction projects (57.7%), industrial construction projects (13.6%), municipal government projects (18.4%) and the other else (10.3%). The sample can reflect the status of construction projects in China well. The age of respondents ranges from 18 to 50, most of them were 31-40, the proportion is 43.1%. In addition, the education backgrounds of them are high school (18.6%), junior college (16.3%) and college (16.9%). With the extensive experience and knowledge of construction management, the respondents can reflect the status of construction management accurately.

PERFORMANCE EVALUATION OF LEAN CONSTRUCTION PROJECTS

PRELIMINARY INDEX SYSTEM OF PERFORMANCE EVALUATION

Compared to conventional industrial companies, construction companies are project-based companies, which organize their structures, strategies and capabilities around the needs of projects (Hobday, 2000; Forman, 2013), therefore, we evaluate the performance of lean construction on projects. Due to the complexity and long-term nature of construction projects, it is important and difficult to establish a comprehensive performance evaluation system. The traditional BSC considers performance evaluation from financial, internal management, learning and growth, and customers, and it contains not only financial benefits but also non-financial benefits, as well as short-term benefits and long-term benefits. Regarding the particularity of the construction project and the definition of the lean construction project performance, we divide lean construction project performance evaluation framework into four dimensions: finance, project management process, knowledge and ability, and owner (as shown in Figure 1). The meaning of each dimension is explained as below.

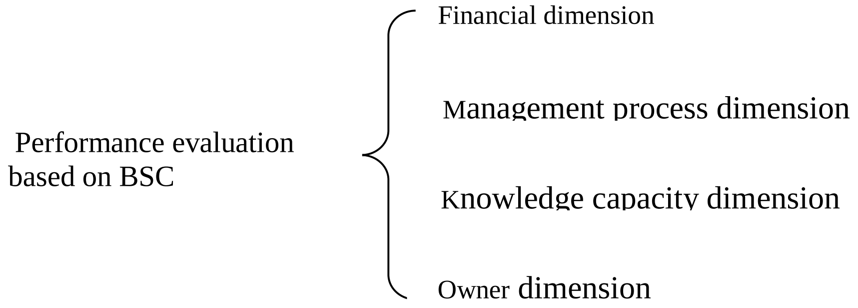

Figure 1: Performance Evaluation Framework based on BSC

Financial dimension: financial dimension means the cost-benefit analysis of the lean construction project. The cost includes direct cost (procurement cost, labour cost) and management cost, and the benefit is main income of the project. Implementation of lean construction brings much benefit to a company, Thomassen, et al. (2003) concluded that MT company in Demark got profit increased by 20%, cost reduced by 15%, and construction time shortened by 10%, the company productivity increased by 25% compared with other construction management model.

Management process dimension: management process dimension is to evaluate the project performance on internal process management, which includes three parts: management, control and coordination. Management contains quality management and safety management, control contains cost control and schedule control, coordination contains coordination with government, owner, subcontractor, community and workers. As lean construction instruments, LPS, TQM and visual management are helpful to improve the construction management process.

Knowledge and ability dimension: knowledge and ability dimension means that the improvement of knowledge and experience of lean construction management, the innovation on construction technologies, and the improvement of construction equipment. This dimension indicates the long-term performance.

Owner dimension: the direct customer of construction project is owner, the final objective of the project is to reach owner satisfactory, which is in accordance with the goal of lean construction, customers value-added. The satisfactory of owner could be measured by complaints or disputes between owner and contractors.

Above all, we established the preliminary index system of performance evaluation (as shown in Table 1), which contained 4 indicators and 18 items. Based on this, we designed the questionnaire to make a survey of some lean construction projects in China, thus we can get the data on the performance of the projects.

FINAL INDEX SYSTEM BASED ON FACTOR ANALYSIS

To properly evaluate the overall condition of the lean construction project performance, we have to analyze and describe it from different perspectives. In many comprehensive evaluation methods, factor analysis method is accepted and given more attention because it can reduce a large number of correlated variables into a smaller subset of uncorrelated variables (Barth, 2008). The main idea of factor analysis is to divide the variables into groups depending on their correlation, and the variables in one group have high correlation while in different groups have low correlation. Each group represents a basic structure, regarded as the main factor or public factor. It is helpful to analyze complex practical problems when we identify a few main factors from the intricate relationship among the elements in the statistics. As the performance evaluation system based on BSC shows strong internal correlation, factor analysis can overcome the impact of the correlation between the indicators on evaluation results, and we use it to build final indicators system of the lean construction project performance. Details are as follows.

Reliability and Validity Analysis

We analyzed the reliability of the raw data by SPSS, the results showed that Cronbach's Alpha was 0.804, and had a higher internal consistency. Then we analyzed the validity of the raw data, KMO was 0.814> 0.5, approximate chi-square was 4138.573, P = 0.000, and passed validity test, therefore, factor analysis could be carried out.

Common Factor and the Final Index System

Selected the principal component as a factor extraction method, the criteria of selected factor extraction was: characteristic value≥ 1. As shown in table2, there are five characteristic values meet the requirement, and their cumulative contribution rate for the sample variance is 59.692%>50%. The results are acceptable statistically and can be interpreted by five common factors.

Furthermore, we should calculate the component matrix for explaining the five common factors, and after the factors rotation by SPSS, we get the factor load matrix. According to the matrix, we can rename the five common factors as knowledge and ability indicators, financial indicators, owner indicators, control in the management process, and management coordination in the management process. The variables of the five common factors are shown in Table 3.

Before evaluating the performance of lean construction projects, we also should calculate the weight of each variable of the final index system. The weight is calculated by the proportion of the variable variance explanation rate to total variance explanation rate.

The formula is as following:

$$\omega_{ki} = \frac{x_i}{\sum_j x_j} \qquad (j = 1, 2, \ldots, n, i = 1, 2\ldots, n, k = 1 \sim 5) \tag{1}$$

Table 1: The Preliminary Indicator System of the Lean Construction Project Performance

Indicators		Items
Financial		Main income is higher than other projects
		Direct cost is lower than other projects
		Management costs is lower than other projects
Managemen t process	Control	The total project overruns
		The sub-project cost overruns
		The completion of schedule for the total project
		The completion of schedule for the sub-project
	Managemen t	Technical specification and functional requirements to meet
		Number of major incidents
	Coordination	Subjected to government or public environmental complaints
		Contract implementation
Knowledge and ability		Technological breakthroughs and innovations in the course of the project
		The development or continuous improvement of templates, procedures, and tools in the implementation of project
		After the completion of the project, participants increase the knowledge and experience of similar projects
		After the completion of the project, participants increase the knowledge and experience of the future cooperation
owner		Owner's satisfaction
		The number of litigation and claims incident with owners
		The mutual complaints rate with the owners during the project

Table 2: Total Variance Explained

Ingredient	Initial eigenvalues			Rotate the sum of squares loaded		
	total	Variance	Accumulatio	total	Variance%	Accumulatio
1	5.105	26.871	26.871	2.761	14.53	14.53
2	2.347	12.353	39.224	2.628	13.83	28.359
3	1.536	8.085	47.309	2.276	11.979	40.339
4	1.228	6.465	53.774	1.857	9.772	50.111
5	1.124	5.918	59.692	1.82	9.581	59.692
6	0.966	5.084	64.776			

Where ω_{ki} stands for the weight of the i-th variable for k-th indicator; x_i stands for the variance explanation rate of the i-th key variable for k-th indicator. Based on the factor load matrix, we calculated the weight of each variable by the formula. They are shown in the last row of Table 3.

Table 3: The Extraction Factor Results of Lean Construction Project Performance

Common	Variables	Weight
The first main factor Knowledge and ability indicators	Technological breakthroughs and innovations in the course of the project	0.234
	The development or continuous improvement of templates, procedures, and tools in the implementation of project	0.215
	After the completion of the project, participants increase the knowledge and experience of similar projects	0.258
	After the completion of the project, participants increase the knowledge and experience of the future cooperation	0.292
The second main factor Financial indicators	The profits during the construction of the project compared with the industry average	0.370
	The direct costs during the construction of the project compared with the industry average	0.337
	The saving costs during the construction of the project compared with the industry average	0.293
The third main factor Owner indicators	The number of litigation and claims incident with owners	0.396
	The mutual complaints rate with the owners during the project	0.504
The four main factor Control in the management process	The total project overruns	0.270
	The sub-project cost overruns	0.267
	The completion of schedule for the total project	0.220
	The completion of schedule for the sub-project	0.243
The five main factor Management coordination in the management process	Technical specification and functional requirements to meet	0.225
	Contract dispute situation	0.270
	The coordinate handing of problem or disputes in the work	0.269
	Owner’s satisfaction	0.237

RESULTS OF PERFORMANCE EVALUATION

Based on above index system and raw data of lean construction projects, we can calculate both individual and comprehensive indicator score of 300 projects to evaluate their performance. The calculation formula of individual indicator score is as following:

$$F_k = \sum \omega_{ki} X_i \qquad (i = 1, 2\ldots, n, k = 1 \sim 5) \tag{2}$$

F_i stands for the individual indicator score, ω_{ki} stands for the weight of the i-th variable for k-th indicator, X_i stands for the variable score of each indicator in raw data.

The calculation formula of comprehensive indicator score is as following:

$$F = \sum \omega_k F_k \qquad (k = 1 \sim 5) \tag{3}$$

Where F stands for the comprehensive indicator score, ω_k stands for the weight of k-th indicator to five indicators, λ_i stands for the corresponding characteristic values of the k-th indicator, F_k stands for the indicator score which is by equation (2).

We calculated the individual indicator score and the comprehensive indicator score of the 300 projects, the projects with high score are mostly municipal projects which constructed by state-owned enterprises and large private enterprises. The projects with the highest score on individual indicator are shown in Table 4. In table 4, we can find that there are a few projects performing good individual indicator performance with scoring “5”, and projects with different characteristics show different individual indicator performance: some projects only perform good performance in one indicator, such as Shijiazhuang Museum of Art project performs high performance in financial indicator, the Jinan Century Jiayuan 9 Building project performs high performance in control in the management process; some projects perform good performance in several individual indicators, such as Nanjing Transportation Technology Building project performs high performance in knowledge and ability indicator, financial indicator, control in the management process and management coordination in the management process, Beijing 108 State Road Reconstruction project performs high performance in knowledge and ability indicator, owners indicator and management coordination in the management process. The result can distinguish the difference of the projects’ performance and indicates that it is essential to use BSC-based evaluation index system.

DISCUSSION

To illustrate the reason why projects with different characteristics show different performance, we interviewed the projects with high and low performance score, and we found that even though most projects conducted with parts of lean construction, many of them can not implement lean construction instruments well. As is mentioned above, the projects with high performance were mostly municipal projects that constructed by state-owned enterprises and large private enterprises, because these projects funds and other resources were more adequate, the size of the project was large, and they showed a good collaboration spirits, rich working, operating and negotiating experience, and relevant knowledge, so these projects could achieve higher scores in knowledge and ability, financial, property owners, as well as project management and coordination of the supporting departments, enabling the implementation of lean construction technology, and thus achieved better project performance. In addition, some enterprises got a higher score in project performance the same as in the indicator index. For example, the reconstruction of Beijing 108 highway project, Nanjing Transportation Technology Building and Tianjin University of Finance and Economics Teacher apartment project. It could be speculated that there is a certain correlation between the degree of implementation of lean construction techniques and project performance. This paper provided the basis of this speculation, and made premise work to further verify the relationship between the status of implementation of lean construction technology and project performance.

Table 4: The Individual Indicator Performance of Lean Construction Projects

Indicators	Projects	Score
Knowledge and ability indicator	Nanjing Transportation Technology Building	5
	Guizhou Ota River Health Hydropower Station	5
	Beijing 108 State Road Reconstruction	5
Financial Indicator	Shijiazhuang Museum of Art	5
	Tianjin 2011 Airport Economic Zone heating pipe network	5
	Nanjing Transportation Technology Building	5
owners indicator	The Jinan Century Jiayuan 9 Building	5
	Tianjin University of Finance and Economics Teacher	5
	Beijing 108 State Road reconstruction works	5
Control in the management process	The Jinan Century Jiayuan 9 Building	5
	Tianjin University of Finance and Economics Teacher	5
	Nanjing Transportation Technology Building	5
Management coordination in the management process	Xiamen binhu residential homes	5
	Beijing 108 State Road reconstruction works	5
	Nanjing Transportation Technology Building	5

CONCLUSIONS

This research used BSC and factor analysis to construct the evaluation index system which is more comprehensive for its combined finance, project management process, knowledge and ability, as well as owners. Using the index system, 300 projects were evaluated, and the evaluation results found that the score of lean construction project performance is related to its scale and normative. Combining with the normative of technical implementation of lean construction, we find that lean construction project performance have some correlation with the degree of implementation of lean construction technology. Therefore, strengthening the study of relevance of degree of lean construction technology implementation and lean construction project performance is the concerned issue in the future. In addition, comparative study with other evaluation methods, such as fuzzy comprehensive evaluation, neural network, data envelopment analysis, etc., is worth further exploration.

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ORGANIZATIONAL POWER IN BUILDING DESIGN MANAGEMENT

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ABSTRACT

In every new building project, there usually is a new organization assembled that needs to function as a team. The organization will vary through the project. This paper analyses the organizational sources of power in the design phase, using 14 main sources of power in organizations as described by Morgan (2006).

The methodical approach of this paper is a single case study, with interviews of participants in the building design phase who describe their experience with the sources of power in building design.

The aim of this pilot study is to learn more about how the sources of power appear in the building design process. Much has been written about how power works in static organizations but less in the context of building design teams and how this affects the design process. This paper contributes with new empirical research. The key finding is that the sources can be regarded as strength, a challenge or a threat to the design process. This knowledge can be used for the design manager to set up a design process. To enhance the sources that strengthen and to diminish the sources that threaten the process, a more efficient design process can be achieved, increasing value and reducing waste.

KEYWORDS

Design management, organizational power, value, process, last planner

INTRODUCTION

The building design process can be viewed in a simplified way as transforming ideas and thoughts to a practical solution for both the construction team and the client. The organization of the building design team will vary throughout the different stages of the design phase, in order to solve the different challenges in a best way possible, maximizing the value for the client. Value can be regarded as something that improves the project, either at the final product or in a successful process (Eikeland, 2001). Power (organizational) is recognized by some organizational and management

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theorists as an important factor to explain organizational affairs(Morgan, 2006). It is therefore likely to assume that power also has a great impact on the building design process and its management, yet there is done little previous research on the subject. The aim of this pilot study is to learn more about how the sources of power appear in the building design process.

BACKGROUND

Building design

In order to describe the process of building design it is important to start at the beginning. The process usually starts with a client having an idea, a need, a property or a combination(Blyth and Worthington, 2001).

Typically the client will engage an architect in order to help him explore the feasibility or options of his needs. During this process the client and the architect end up with a building program or definition for the project. The design phase is important in order to create value for the project (El. Reifi and Emmitt, 2013; Hansen and Olsson, 2011).

There are different approaches to manage the building design phase. This could be based on lean construction principles as e.g. Last Planner, were the designers plan and re plan their own work (Hamzeh, Ballard and Tommelein, 2009). This is also the basis of CDM (Collaborative design management), and CPD (Collaborative Planning in Design) (Bølviken, Gullbrekken and Nyseth, 2010; Veidekke, 2013; Fundli and Drevland, 2014). The use of VDC (Virtual Design and Construction) is another approach to improve the building design phase (Kunz and Fischer, 2009). With the use of ICE (Integrated Concurrent Engineering) you can reduce latency in the design process by involving the right stakeholders and working on specific issues together (Mark, 2001; McManus, Haggerty and Murman, 2005; Kunz and Fischer, 2009; Choo and Fischer, 2010) .

Typically new buildings are organized as projects. “A project is a temporary endeavour undertaken to create a unique product, service or result”(PMBOK, 2004). Regardless of contract form the most usual way to organize a project is trough agreements on a company level and not on a personal level. The professionals representing their company are then “teamed“ together with the other companies’ representatives. This means that the organization is often new and unfamiliar at each new project. The organization will also vary throughout the project. “Organizations are coalitions and are made up of coalitions, and coalition buildings is an important dimension of almost all organizational life.” (Morgan, 2006)

Organizational power

Killian and Pammer (2003) describes power as “one party´s attempt to impose an outcome on the other party”. Power can be exercised at an individual level or as a group (Killian and Pammer, 2003; Engelstad, 2005). In all organizations the power balance of the stakeholders will influence the work and processes. The design process, as an open, creative process is a difficult process to control for a design manager (Knotten, et al., 2015). Will the power imposed by stakeholders be more or less influential in a design process than in other processes? How will this affect management of the design process? Does it increase the design manager’s power or make him powerless? Powerlessness is if the manager lacks resources, information, and the decision making authority (Ivancevich, Matteson and Konopaske, 2013). Should the power be spread in the team? Empowerment is sharing power and authority with subordinates to increase their confidence and effectiveness (Ivancevich, Matteson and Konopaske, 2013).

There is written much about power in permanent organizations. Even though they address the same issues they seldom define the sources or interactions in exactly the same way (e.g. Daft, 1997; Engelstad, 2005; Morgan, 2006; Ivancevich, Matteson and Konopaske, 2013). This paper does not dwell directly on the different ways to describe power but looks at 14 different sources of power predefined by Morgan (2006). The definition of Morgan (2006) was chosen because of the more explicit definition of the sources makes it easier to compare with the building design context. The 14 sources of Morgan (2006) are listed and explained below;

1. Formal Authority; can consist of different types of authority, such as legitimate authority, charismatic authority, traditional authority or rule of law.
2. Control of scarce resources; means to have control of special competence, products or funding.
3. Use of organizational structure rules, regulations and procedures; is a structure to ensure the right power at the right actor, yet it also can be a source power if played right.
4. Control of the decision process is an important power source. Controlling the decision premises, process, issues and objectives can give someone a big influence.
5. Control of knowledge and information. The ability to gain knowledge and information and control it creates a power situation. Being able to control who gets the information and when, creates a dependency for the rest.
6. Control of boundaries. By creating and controlling boundaries you can control the information going between groups, which enables you to control the information. This can be done trough blocking some information and encourage some.
7. Ability to cope with uncertainty. The ability to cope with uncertainty has always been seen upon as a key managerial characteristic. Morgan (2006) describes uncertainty as an environmental uncertainty and operational uncertainty. The environmental uncertainty is the external influences that affects your organization, and the operational uncertainties are the once that’s influences you directly. Ivancevich, Matteson and Konopaske (2013) lists 3 ways of dealing with uncertainty, coping by prevention, coping by information and coping by absorption. Coping by prevention means to reduce the probability of some difficult to happen, coping by information is the ability to use information to forecast what will happen and then be prepared. Coping by absorption is to deal with the uncertainty as it appears.
8. Control of technology. The rapid change of technology and our dependency of it make us both vulnerable and make technology a source of power. Technology influenced work placed in a sequential dependency, makes the whole process vulnerable to the function and operation of the technology

9. Interpersonal alliances, networks and control of informal organizations. Informal alliances and networks can be staged or coincidental. They can be developed in the organization or in spare time. The effect these informal alliances can have on the organization will vary. These informal networks can affect the organizations in different ways, both positively and negatively.
10. Control of counter organizations. Whenever a small group of people manages to build up a concentration of power, it is not uncommon for the opposing forces to organize themselves to rival power. This is typically how the unions were established, trying to establish a counterbalance
11. Symbolism and the management of meaning. An important source of power is how you can persuade the others to follow your lead and intentions.
12. Gender and the management of gender relations. “Many organizations are dominated by gender-related values that bias organizational life in favour of one sex over another” (Morgan, 2006).
13. Structural factors that define the stage of action. Even though you have a personal power trough e.g. legitimate authority the structure of your organization might limit your possibilities to do as you wish.
14. The power one already has. Power is a route to power and can help one to achieve more power either by using the power to manoeuvre yourself right or by others allowing you to lead them.

METHODICAL APPROACH

In order to study the sources of power in building design organizations the research was designed as a case study. The focus of the research was to learn more about how the sources of power appear in the building design process. This argued for a qualitative research approach. Qualitative research is focused to get an in-depth understanding of human behaviour and of the circumstance around (Creswell, 2003). This is best achieved with the perspectives from those who are studied (Crewell, 2003; Alvesson and Sköldberg, 2009).

The research was set up as a single case study, by using semi-structured interviews with participants of building design projects (Creswell, 2003; Yin, 2014). The interviews were audio recorded and transcribed over a period of a month giving the researcher an opportunity to reflect and improve the next session (Kvale and Brinkmann, 2009). The interviews were conducted in two different ways with 5 persons. The first way was to talk about the building design process in general with out mentioning any of the 14 sources and the second way was specifically to ask in reference to the 14 sources. Both approaches gave interesting information, but the latter was easier to code afterwards.

The five persons had different educational and working experience. There were 3 female and 2 male persons. All the Design managers (DM) were currently employed by the same Norwegian constructor, but working at different projects (see table 1). Even though 5 persons is not a large data sample both Flyvbjerg (2006) and Ragin and Becker (1992) argues that also a small number of cases will contribute to new and important learning.

The analysis of the interviews is based by on the six steps of Creswell (2012) as a variant of the constant comparative method as described by Corbin and Strauss

(2008). The coding ended up as a mix of using the 14 sources as codes and other codes that emerged through the analysis. For this paper the analysis is concentrated around the 14 sources of power. The findings were then arranged in a matrix to be able to compare the informants view towards the 14 sources.

Table 1: Case study subjects

Subject	Design Manager	Design Manager	Design Manager	Design Manager	Architect
Work Experience	7 years. As a consultant and constructor	17 years. As house builder, architect, and constructor.	23 years. As consultant and constructor	22 years. As consultant, governmental agencies, and constructor	10 years. As an architect

RESULTS

The key findings are presented in this chapter.

The informants identified the client as the formal authority in projects, acknowledging the legitimate authority. *"What the client wants he gets."* It is important to have a formal authority in order to be clear about who makes different decisions and that the role is executed dynamically throughout the project. The formal authority of the design managers was commented more as "*a source of power to influence the solutions*" than as a formal authority.

The informants emphasized the major scarce resource as time. Short time between contracts and the construction start could put the design period in a squeeze, yet this could also be interpreted as a lack of sufficient resources available. This makes it important to get a design team started as early as possible. Scarce resources in form of low budgets might lead to sub-cultures and sub teams.

The informants emphasize the important of a well functioning team. To be efficient the design organization needs a flat structure and to be transparent. The transparency regards to an open and clear understanding of everyone's responsibilities and tasks in the project. The organizational structures need to be formalized to have well functional teams.

Designing is very much about the decision process and the informants agreed on that fact. To ensure the right decisions at the right time the informants agreed this process needs to be planned and that the results of the decisions informed to the team members. As a design manager said: *"All client decisions were in the plan together with permit applications, and drawing deliveries. By a common run through of the plan every week, everyone was aware of what decisions that had to be made."* It is important for the design team to agree on what decisions can be made by team members and which needs to be addressed in common. The results of the different decisions need to be informed to the whole team.

The design manager needs to have the total knowledge to be able to manage the process, but also the designer need to have knowledge of what the others are doing. As an informant described the work as a junior engineer "*I just got handed a scope of my work (MEP) and a finish date. This was executed with little concern of other trades."* There is also a possibility that you withheld knowledge of new technology in order to reuse old solution in order to save your fee. *" I have the enough experience* *to solve this problem, but with the time and this scope I´d rather present something I´m comfortable with"*

Controlling boundaries and interfaces is a challenge in the design process. One of the design managers allocates responsibilities between the designers by making a matrix with the most common interfaces. *" It is important to balance and acknowledge the different interfaces in the project but also to keep an openness to cross the borders and to learn from each other. If you understand the challenges of the others then you better can solve them. "*

One of the most challenging boundaries is between the design team and the production team. To get the foreman's attention into the drawings process and be a proactive asset, instead of the latter complaining. As one design manager said: *"the production (team) don´t see how much better the design result could have been if they´d only participated a little in the design"*

Even though uncertainty in design cannot be removed all together, the informants agree that planning can reduce it considerably. The planning process needs to be collective. The more involved the team members are in the plan the better the plan is. As a design manager said about collaborative planning: *" It is not the mapping process, but the discussions that are important "*

Being able to use the new technology and tools of e.g. BIM might give you or your organization an advantage in a project. At the same time if your do not know how to use the technology you are obsolete and might miss out on opportunities. Investing in technology cost, but can give some crucial advantages. The aspects of technological challenges in a design process can vary. It can be from design tools as BIM, to process tools as collaborative planning and to actual construction tools as new materials, a new concept of structure etc.

By the informants there is an acceptance that the control of technology must be trusted to be with the different team members, all the time they are specialist. A poor or a low compliance solution with the project needs would result that they were not reengaged in other projects. Yet the informants came back to an open, common team culture so the knowledge and technology is spread.

Informal networks could work both ways. As an informant said *"Knowing people in the business, who to call, who is positive is important. Phoning the right clients representative is crucial to get the first meeting "*

Trying to pin down counter organizations in the design phase was one of the questions that were least coherent. It was recognized that there are a lot of actors in the process who have a sub-agenda of the project´s. This could e.g. be personal agendas, or a goal to make money for your employer on expense of the project.

The informants agreed that symbolism is not at typical sources in the Norwegian AEC industry. As one said, *" I think it is a pretty casual and democratic platform and structure"*

The AEC industry is male dominated but the female informants felt that they were almost never treated different because of their gender. Episodes that had happened were linked when they were newly educated and happened many years ago. Their opinion was that you are much more judged by your knowledge and attitude than by gender. Yet the male informants felt that there was discrimination in the Norwegian AEC industry. As a male design manager said; *"I´m a blue eyed middle-aged guy* *working as a design manager in a construction company. Do you think I´d this job if I were a middle-aged woman from the Middle East? "*

One of the most important structural factors is that the AEC industry is project based and the fact that members of the design team changes for each project. This makes the contracts structures important, but especially also the way clients are organized. E.g. a private real estate developer has a short distance between decisions and money, while most public companies have rigid structures and forms of decision-making. This can lead to a culture of " insecurity" and long decision time.

The power one already has will influence the design process in some degree. If you are the client or the formal leader this will enhance your power. Are you on the other hand an architect or consultant this might result in a poorer process and creation of a counter organization. As one informant had experienced: *"The architect was strong and forcing his solutions on the design team. He was able to do this since the team didn´t know each other well."* This didn´t contribute to the projects goal and wishes and created an extra challenge for the design manager.

DISCUSSION

It is difficult to clearly divide the influence of the power sources in the design phase into Morgan's 14 sources. One power source may have a direct or indirect influence on the other sources and the momentum of the sources varies as well with the stages of the design process.

Through the work with analysing the material, the main focus was how the organizational sources of power appear in the building design process. A natural step was to look at how they influence the design process. Through the analysis we found that the sources of power influenced the process in three major ways. They could contribute to strengthen the process. Several of the sources represented the main challenges in the design process and some also represented a threat to the design process.

There are sources that are important to empower the design manager. We could refer to these sources as strength. These sources need to be addressed and organized so they support the management process. These are typical: Formal authority, the use of organizational structures, symbolism and the management of meaning, structural factors and the power one already have. The informants felt that the structure and roles should be clear to everyone.

There are sources that directly influences the design processes and creates challenges to control. These are control of scarce resources, decisions, boundaries, technology, information, and to cope with uncertainties. From the informants it was emphasized the importance of transparency in the design process to diminish the sources negative effect on the process. By involving every team member in the planning process, by using e.g. Last Planner, CDM, CPD the informants felt that the transparency increased, everyone had agreed on critical decisions points, and the interfaces were discussed in advanced. In newer approaches such as ICE where all important stakeholders are present, the negative power of decisions processes are reduced.

A common opinion by the informants is that time is a scarce resource in the design phase. With parallel design and construction leading to "fast-tracks" initiative the time aspect influences the whole design team. This again influences decisions, knowledge transfer, uncertainty and boundaries.

There are also sources that can work against the management and the design process. These sources create a threat to the design manger and are; interpersonal alliances, counter organizations, gender issues, and powerful individuals. These can create sub-cultures, which are different of the project goals. The informants emphasized the importance of the design team. It is important to get the different members of the design group to function as a team and to establish common cultures, and goals. This is coinciding with the work of Bell and Kozolowski (2002) who emphasizes the team and common project culture in complex projects.

The establishment of the design team with a transparent organization and good communication is also identified as a way to diminish and clarify each team member's source of power. By having a good kick-off session the organization of the projects design team is discussed and presented making the formal roles open to all. By a common collaborative planning session like Last Planner everyone is involved in the process, and have to contribute to the process, reducing uncertainties (Fundli and Drevland, 2014). By including a decision plan in this plan everyone knows of and can influence on what decisions need to be taken and when. The transparency in the project organizations helps to keep everyone updated about what the project is about reducing the information "hub" as a source of power. There has been some efforts in trying to increase the information flow in projects (e.g. (Loría-Arcila and Vanegas, 2005; Thibelsky and Sacks, 2010) These have the focus of e.g. reducing bottle necks, which is a source of power. A bottleneck of information usually occurs when a lot of information has to go through one or a few people. A good tool to share information and knowledge is Integrated Concurrent Engineering (ICE). A strong coherent team will also be less side-tracked by informal or counter organizations.

CONCLUDING REMARKS

This paper describes the sources of power and the influence they can have on the design process. To the design process the sources can be viewed either as a: (See Table 2)

- Strength - where the sources contributes to empower the management
- Challenge –where the sources directly influences the design process
- Threat – where the sources contributes to create powerlessness

By investing time in building a good team and using tools as e.g. Last Planner and VDC you are able reduce the sources of power that can create problems for the design process. By enhancing the sources that empowers the management you strengthen the design process. If you reduce the sources that threaten the process you will reduce waste in the design process. By first dealing with these sources the team can better focus on the sources creating challenges for the design process.

The knowledge of how organizational power appears in the building design process can be used for the design manager to better organize the design process. By focusing on how the sources of power influences the process a more efficient design process can be achieved increasing value and reducing waste for the project.

We acknowledge that this is a limited case study concerning the topic and that a future next step would be to compare the findings with other management literature.

Table 2: Summarizing the findings.

	Source of Power (Morgan, 2006)	Influence	Tools
Strength	1. Formal Authority 11. Symbolism and the management of meaning 13. Structural factors that define the stage of action 14. The power one already has 3. Use of organizational structure rules, regulations and procedures	Increase the control for the Design manager	Good teams
Challenges	2. Control of scarce resources 4. Control of the decision process 5. Control of knowledge and information 6. Control of boundaries 7. Ability to cope with uncertainty 8. Control of technology	Reduce Impact on the design process	Last Planner, CDM, ICE.
Threats	10. Control of counter organizations 12. Gender and the management of gender relations 9. Interpersonal alliances, networks and control of informal organizations	Reduces the control of the design manager	Good Teams, ICE, CDM, Last Planner

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GUIDELINES FOR PRACTICE AND EVALUATION OF SUSTAINABLE CONSTRUCTION SITES: A LEAN, GREEN AND WELLBEING INTEGRATED APPROACH

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ABSTRACT

Sustainability is addressed through the triple bottom line concept, bringing together economic, environmental and social issues, related management actions and their impacts for better building sites. Lean concepts are incorporated into the economic side of the model, while a new concept – wellbeing – expands the social pillar. Green attributes render themselves naturally to the environmental part of the triple bottom line approach. A model to evaluate how and in what degree lean, green and wellbeing concepts are being applied in site layout managing is developed using Design Science Research (DSR) propositions. This procedure is tested in three different sites in the city of Fortaleza, in the Brazilian northeast region. Results point out that the model artifact obtained through DSR is capable of synthesizing a huge number of variables both in terms of possible management actions and in terms of their sustainability outcomes. Graphical displays help to guide how sustainability might improve over time, either evaluating individual sites against their previous records or benchmarking different building projects.

KEYWORDS

Sustainability, triple bottom line, lean construction, green, wellbeing, performance evaluation.

INTRODUCTION

Construction industry is characterized by a huge consumption of natural resources and its potential environment degradation. While in the course of transforming the natural environment into a built environment, many hazardous impacts can be identified throughout a project life cycle (Agopyan and John, 2011). At its onset, a

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sustainable site might be a first good step towards an overall better project performance.

A sustainable site would provide a more significant impact on society if the triple bottom line approach is taken, bringing together its economic, environmental and social benefits. Further down, once the building site is handed over, after its several construction stages are completed, the triple bottom line approach should be enforced throughout commissioning, operating, refurbishing and finally dismantling the building after its service life (Piccoli, Kern and González, 2008).

Customers growing demand for sustainability has been introduced as a strategic concern to higher levels of developer's managerial staff and gradually spread to operations on site (Pardini, 2009). However this effort has generally narrowed down to green concepts, to building product design, to waste control on site and to the adherence to public or private codes of practices as the LEED assessment. A truly systematic triple bottom line effort as proposed by Elkington (1999) aiming at establishing guidelines for a sustainable building industry is still lacking. Further down this research work discusses why disciplines like Lean Thinking, Green Building and Social Impacts of the construction activity, taken individually or as combinations, are not enough to support the more encompassing triple bottom line view. Wellbeing concepts are brought to light in order to fill this gap.

LEAN, GREEN AND WELLBEING: AN INTEGRATED APPROACH TO CONSTRUCTION SITE

The Lean Thinking research community spread its academic reasoning's to different areas like supply management, design management, health and safety, building maintenance and building refurbishment, widening initial concerns restricted to production planning and control. It was a natural step to accommodate the concurrent green concept under its value umbrella. This is equivalent to credit environmental concerns to clients' needs in the previous Quality Movement research thrust. A more careful research methodology is first to identify similarities between Lean and Green, Lean and Sustainability, Lean and Health & Safety, and Lean and Social Responsibility and then proceed towards the meritorious scientific goal of identifying a common or a leading knowledge discipline.

Ng, et al. (2010) related lean and safety using a set of indicators to assess safety performance, demonstrating the positive impacts of a lean environment to the reduction of hazards on site. At that moment, Slivon, et al. (2010) claimed a deeper human concern in Lean Thinking. Benefits to internal human employees or to external human needs and desires should be taken as the primary end result of managerial efforts and not just as another issue that should be systemically contemplated, whatever its relative importance in a building company strategy.

Chronologically in the following year, papers by Alarcón, Acuña and Diethelm (2011); Antillón, et al. (2011) and Leino and Elfving (2011) elected the positive impacts of Lean Construction to Health & Safety as a testimony of the former wide-ranging effects. On the other hand Salvatierra-garrido and Pasquire (2011) and Vieira and Cachadinha (2011) contributed with Lean and Green evidences on conceptual interactions.

Wellbeing, according to Ryan and Deci (2000) and Sen (1993) encompasses motivational and self-determination, both individual and collective satisfaction, involvement with company's values and shared vision. It derives from anthropological findings on how humans have evolved, but accepting psychological views on how man behaves according to a specific culture. It has been incorporated into managerial techniques through psychologist and sociologists observations on how man is motivated and reacts while performing work. It might be comprehensively addressed with guidelines derived from the discipline of Quality of Working Life (Walton, 1973).

For the purposes of this research work Wellbeing concepts are needed to provide a proper building site, according to the following reasoning. Lean guidance would organize a site with a rational layout while green (and sustainability) would minimize the consumption of resources and adequate discharge of them. Quality of Working Life would dictate the provision of a legally sound, socially encouraging, individually defying environment. This is not enough according to Wellbeing: a proper site is a place where individuals want to be, feel at home, and find out the necessary support to develop their selves. This is the kind of atmosphere that is associated with craft work of self-employed artisans, being illustrated by Sennet (2009; 2012).

Failing to obtain relevant literature on the interaction of Lean, Green and Wellbeing it should be mentioned, in the search for methods of integrating different knowledge disciplines, the recent works of Rosenbaum, Toledo and Gonzalez (2012), Carneiro, et al. (2012) and Campos, et al. (2012) provide a performance assessment model to evaluate the maturity of use of sustainability and LC.

Reinforcing the methodological approach rather than the quantitative findings on possible interactions Valente, Mourão and Barros Neto (2013) proposed a coherent application of lean and green concepts on building developments at the strategic, tactical and operational level. Salem, et al. (2014) analysed the commanding role of Lean Construction on a triple bottom line approach to sustainability, but social impacts on sustainability are again restricted to Health and Safety issues.

It is clearly necessary to step further in this social perspective, and this is where the Wellbeing concept might provocatively help. For example cell production promotes employee's empowerment, what can be introduced as one more item in a triple bottom line checklist using the already mentioned Quality of Life at Work concepts. Wellbeing would go further, expressing the positive feelings related to the possibilities of alternatively using power or accepting a subordinate relationship at work. Moreover, wellbeing would suggest investigating how much cell production workers feel comfortable performing teamwork.

Degani (2003) puts forward a matrix to evaluate environmental actions and their corresponding impacts on a building development. Araújo (2009) employed this matrix to contemplate best practices found in a number of building sites and their possible effects on sustainability. This research work uses the matrix and checklist techniques to address the problem on how to evaluate lean, green and wellbeing actions on building sites. However, it recognizes that such approach leads to extensive lists of actions and extensive lists of impacts, magnified now for this endeavour of comprehensively addressing a more balance view on economic, environmental and social aspects.

METHOD

Design Science was used as a research strategy to create a solution to the following management problem: how to create a method to integrate a list of actions derived from Lean, Green and Wellbeing with their potential impacts in economic, environmental and social outcomes, leading jointly to a more sustainable building site. Such administrative tool should take into account that site administrative personnel might freely hypothesize actions and associate impacts. They might choose actions and outcomes according to what is deemed adequate to different stages of progress on a building site and what such management personnel understand as appropriate to obtain sustainable outcomes. Moreover, if site personnel decide to embark in less time-consuming evaluations, they should feel free to choose a restricted set of actions and impacts.

Design Science (DS) is a research strategy that creates and evaluates artifacts intended to solve identify organizational problems (Hevner, et al., 2004). This approach is eminently focused in solve practical problems instead of analyzing nature laws or compartmental theories (Collins, Joseph and Bielaczyc, 2004). Even if this artifact is not entirely sound in theoretical terms, one of the key issues is its operability in practice. The latter is adhered to through a research process containing seven steps, as suggested by Hevner, et al. (2004) is showed in Figure 1.

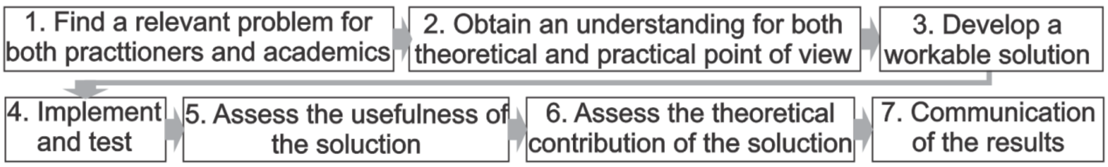

Figure 1: Designed Research Process

MODEL FOR EVALUATION TO SUSTAINABILITY OF CONSTRUCTION SITE

The proposed model is characterized by four different parts: 1) Building Company Characterization; 2) Building Site Characterization - Creation of a Matrix to relate site management actions and sustainability impacts; 3) Calculations and Comparative Graphical Display of Results.

Building Company characterization Styles – Headings

This just a formal procedure to elicit recent developments in the areas of lean production, green building and social awareness of the building company that might be useful to further indicate how far a specific building site is expected to practice sustainability principles. This section might contemplate former strategic plans, TQM procedures, compliance to Quality, Environment and Safety certifications and data and image banks of recent developments with successful implementation of sustainable efforts.

Construction Site Characterization - Matrix of Economic, Environmental and Social Impacts

Following Degani (2003) and Araújo (2009) a list of management actions related to lean, green and wellbeing is produced, taking the form of the vertical axis in a Matrix, like the one displayed in part on Table 1. Note that for the sake of space restriction, this paper produces only part of the management actions connected to environmental actions. On the same token general lean practices are not mentioned apart from the three initial lines related to the management of resources: they are presented in full in Vasconcelos (2013), a M.Sc. Dissertation. Similarly, the last three lines area a short version of the Wellbeing/Social management actions: two of these lines are related to local development, while the central line maintains the tradition of referring Wellbeing/Social actions only to Health and Safety, what was heavily criticized in the initial parts of this research paper.

Table 1 - Part of Matrix of relevant aspects versus environmental impact of construction site (A x I Matrix)

Company:		Interviewed/ fuction:										
Construction Site:		Type of construction project:										
MATRIX OF ENVIRONMENTAL IMPACT OF CONSTRUCTION SITE		Economic, Social and environmental impacts										
		Physical environment										
		Soil				Air		Water				
Category	Sustainable aspects	Impact on physical properties	Chemical contamination	Induction of erosive processes	Depletion of mineral reserves	Deterioration of air quality	Noise Pollution	Impacts on surface water quality	Increase of solid quantity	Impacts on groundwater quality	Impact on flow regimes	Water scarcity
Management of Resources	Consumption of Resources (includes built-in loss and packaging)											
	Consumption and waste water											
	Consumption and energy waste											
Nuisances and pollution	Generation of dangerous waste											
	Generation of solid waste											
	Vibration emission											
	Sound emission											
	Release of fragments											
	Emission of particulate matter											
	Risk of sparks generation about dispersed gas											
	Release of gases, fibers and other											
	Air renewal											
	Management of dangerous materials											

The Matrix of relevant aspects versus environmental impact of construction site (A x I Matrix) shows a list of 34 possible management actions divided into 5 major subcategories: management of resource, nuisance and pollution, construction waste, infrastructure of the construction site and social issues.

Calculations and Comparative Graphical Display of Results

Table 2 exemplifies how scores are obtained within the matrix format. First, a notation is used to subjectively assess impacts of a line into a row. A circle describes a substantial impact while an X implies that just a simple impact is expected. If nothing is added to a cell it means that no relationship is foreseeable for the pair of line and row variables. A management action described by a line will have a really significant (superior) impact on the array of sustainability variables if the number of circles is greater than the number of Xs (and this scores 3). An intermediate impact is associated with the number of circles equal the number of Xs (and this scores 2). A basic impact is associated with the number of circles smaller than the number of X (and it scores 1). This scoring scheme is subjective and might be changed by prospective users; care should be taken to maintain the same scoring system when comparing different building sites.

Table 2 – Example of matrix of environmental impact of construction site

MATRIX OF ENVIRONMENTAL IMPACT OF CONSTRUCTION SITE		Economic, Social and environmental impacts												
		Anthropic environment												
		Employee		Neighbourship								Society		
Category	Sustainable aspects	Change in health and wellbeing	Change in safety conditions	Change in landscape quality	Change in health conditions	Nuisance to Neighbourship	Change in traffic on local streets	Pressure over public urban services (except drainage)	Changes in security conditions	Damage in others buildings	Interference in urban drainage	Pressure over public urban services (except drainage)	Increase the volume of waste in landfills	Interference in urban drainage
Social Issues	Development of labor-hand own, subcontractors or suppliers	O	O		X				X					
	Development of Safety and health	O	O	X	O		X		O					
	Local development		O	X	X	O	O	X	X	X	O			

The comparative graphical display of results is obtained like follows. Abscissa values represent how much management actions might impact sustainability. They are taken as the sum of all scores for possible management actions. For Figure 2, with 34 possible management actions maximum score, will be 34 * 3 = 102 and minimum will be 34 * 1 = 34. An interpretation for this range of values is: if all management actions are expected to have a number of substantial impacts greater than just simple impacts, this building site is characterized, potentially, by a substantial outcome in terms of sustainability. On the other hand, if all possible management actions (lines) are classified as 1, basic impacts, not very much can be expected in terms of sustainability outcomes. Note that abscissa values cannot be smaller than 34 for figure 1. If a management action has no impact in any sustainability variable it should be removed from the check-list, as all cells combining this line and the respective rows for impacts will be empty. Further to that abscissa values are standardized in the range zero to 100, taking for this case 34 as zero and 102 as 100.

Ordinate values represent what is being achieved on a particular building site in terms of sustainability. It is based on the GBC accreditation scheme (Silva, 2007) using a Likert scale with 6 points as proposed by Backer (1995) and Siqueira (2008). Site administrative personnel will fill again Figure 1 matrix, now evaluating actual impacts of every management action into row sustainability variables. As before, each management action might have a superior, an intermediate or a basic actual impact. Unlike the previous abscissa discussion, it might happen that a particular management action, deemed to impact some sustainability variables is not showing any impact: in this case, actual impact is represented by empty cells throughout this management action line. This would be associated with a zero score.

A relative scoring scheme is illustrated as follows. It might be that a management action line that is supposedly of basic nature (score 1), now is actually producing a greater number of substantial impacts (score 3). Its relative score would be +2, that is (3-1). Contrariwise, a theoretical superior management action line (score 3) might be actually producing a greater number of simple impacts (score 1), what would be associated with a relative score -2, that is, (1-3). In the case of a management action line not actually showing any impact (with all line with empty cells), its relative score would be -3, -2, and -1, respectively if it was initially associated with a potential superior impact (score 3), an potential intermediate impact (score 2) or a potential basic impact (score 1).

RESULTS AND DISCUSSION

Figure 2 plots global scores for sites A, B and C. Site A has a minimum standardized score of 75 and was able to achieve an actual standardized score of 79. It means that site management was of the view that potentially this site could positively affect 75% of all sustainability variables presented in Table 1.

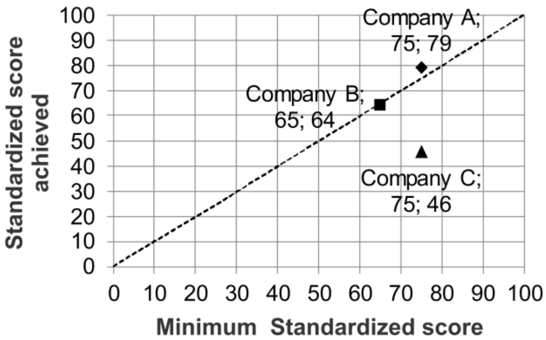

Figure 2: Comparative analysis to each company

This figure is either what could be theoretically possible for this site and its characteristics, both in terms of sustainability requirements and management actions that were under course, or alternatively, management actions and sustainability requirements this site is committed to address. This second option is an interesting methodological characteristic of the proposed method: while analysing individually a site, standards are set by its own managerial staff, instead of following a checklist that is externally imposed.

Site B committed itself to pursue a set of management actions that would theoretically impact 65% of the sustainability requirements set in Table 1. In actual terms, this site was able to achieve 64% of the sustainability requirements, just under the figure it was committed. Note that in actual terms it might be, for example, that this site is getting better than committed impacts due to lean actions, and worse than committed for the other areas: in sum, notwithstanding some differences between theoretical and actual performance, the site is delivering sustainability as planned.

Site C is not sustainable according to its own standards. Its management staff committed itself to affect positively 75% of all sustainability requirements in Table 1 but it was able to deliver only 46% of them.

Radar charts as presented in Figure 3 allow site personnel to depict weaknesses and strengths of its sustainability management system at a glance. Moreover, they call attention to the lack of balance between what was theoretically envisaged and actually achieved. For project A infrastructure of the construction, for project B this and construction waste and for project C all subcategories apart from infrastructure of the construction site are unbalanced. It might be said that projects A performed well and project B was just under what it was committed to, but they were able to achieve their results due to performance counterbalance between subcategories.

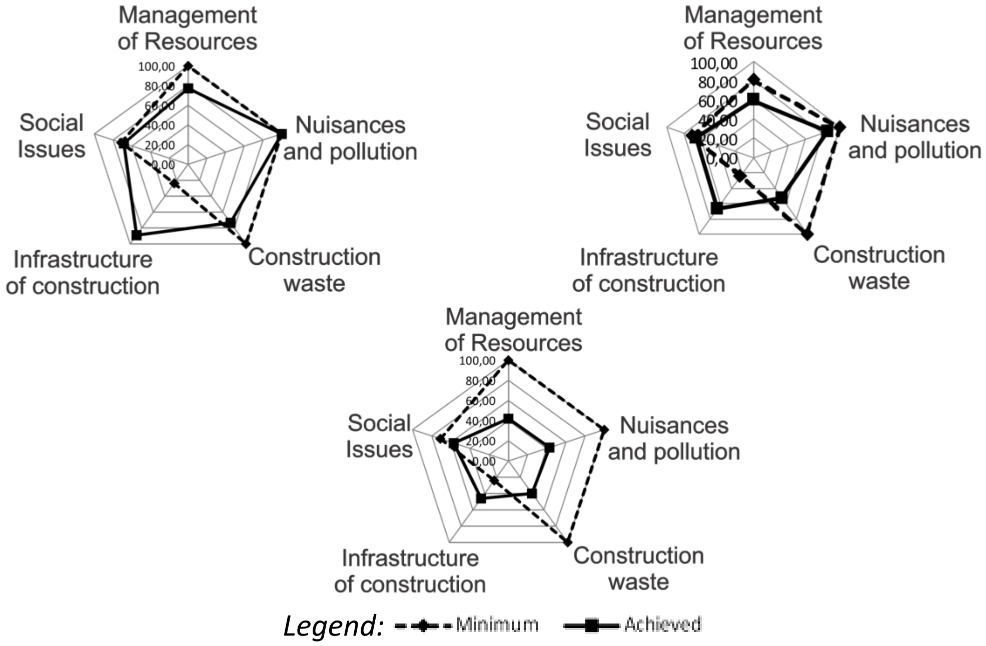

Figure 3: Scores to each category for company A, B and C respectively

FINAL REMARKS

This research work demonstrated the construction of a new artefact to evaluate sustainability on construction sites, following the triple bottom line approach. Suggestions were made to incorporate lean management actions into the economic triple bottom line pillar. Management actions leading to a green site were naturally associated with the environmental pillar, while a new concept, wellbeing, was introduced to expand the social pillar.

Design Science Research provided the methodological background to build a matrix like kind of tool to make it simple the amalgamation of an overwhelming number of possible site management actions and their impacts on sustainability requirement. A synthetic view allows one to evaluate the degree of sustainability a site is able to achieve according to what it commits itself to achieve. This perspective of judging performance according to commitments, weaker or stronger as they might be, is deemed appropriate to help introduce such evaluations on site, without the imposing requirements of external control, whereby standards are set by actors that are not responsible for the daily site operations.

A suggested scoring scheme induces management to select a balanced set of management actions than otherwise it would be possible by just summing cardinal scores for the potential impact of management actions into sustainability requirements.

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POST MEASURING THE LAST PLANNER METRICS IN SHELTER REHABILIATION PROJECTS

Mahmoud S. El Jazzar[1], Farook Hamzeh[2]

ABSTRACT

The Last Planner System (LPS) implementation showed great results in improving workflow for construction projects. In order to apply LPS, companies must collect key metrics on site; such data include Percent Plan Complete (PPC) for tasks done on site.

In this study, ten shelters from "Self-help" rehabilitation project were monitored. To identify workflow issues and highlight causes of delay PPC was measured for the duration of the project. This study is a personal effort to assess the reliability of workflow in the light of the fact that contractors do not apply the LPS.

The results showed that "Self-Help" delivery method promoted lean behaviour in families who were engaged in the rehabilitation process. They tackled constrains, expedited the work and organized construction activities in sound manner; thus, achieving high PPC. However, families who did not engage in rehabilitation process failed to finish their shelters on time, and achieved a low PPC. Reasons for incomplete weekly tasks were recorded and analysed.

The main goal of this on-going research is to improve workflow of UN projects, highlight causes of delays, and add value to refugees by removing impediments to construction workflow so that projects can be finished sooner and at a lower cost.

KEYWORDS

United Nations, PPC, work flow, self-help, LPS, agile.

INTRODUCTION

The Last Planner System® (LPS) is a production planning tool that is used on construction projects. LPS is better than traditional project management approach as it involves downstream players, focuses on the production system, incorporates learning into all project stakeholder, shifts focus from the end product of activity to the link between activities, and embraces continuous improvement (Ballard, 2000).The LPS is composed of 4 integrated planning elements: Master plan, Phase plan, Look ahead plan, and Weekly work plan (Ballard, 1997).

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The last planner improves productivity when properly implemented (Liu, Ballard and Ibbs, 2011). Its main goal is to reduce workflow variation and pave the way to optimization (Zimhna and Pasquire, 2012). LPS became equivalent to Lean, and it is considered the main tool which makes Lean applicable to construction (Green and May, 2005; Jorgensen and Emmitt, 2008; Rybkowski, 2010). In order to successfully apply LPS, the following actions must be performed: plan in more detail as you get closer to executing the task, create plans with those who will perform the work, eliminate constraints on planned tasks, make reliable promises, and learn from breakdowns (Ballard, Hammond and Nickerson, 2009). LPS primary role is to reduce variability in workflow, thus clearing the way for process optimization, and productivity improvement (Zimhna and Pasquire, 2012).

Figure 1 shows the reduction in project duration when implementing lean on construction projects in different countries.

Country	% of improvement (Duration Reduction)	Used Lean techniques
United States (US)	16%	Last Planner System, Visualization management & First run studies, 5S, and fail safe for quality & safety
Brazil	25%	Last Planner System
Nigeria	31%	Last Planner System, Visualization management & Huddle meetings
United Kingdom (UK)	37%	Just-in-time, collaborative planning, visual management, prefabricated material, Waste elimination, 5S, theory of constraints.
Sweden	79%	Last Planner System, continuous improvement, Value Stream Mapping, Pull approach, reduce batch size, Just-in-time, collaboration, and prefabricated material.

Figure 1 - Effect of implementing lean approach and realized benefits in different countries (Swefie, 2013)

A cornerstone for improving project planning is measuring PPC, identifying reasons of incomplete activities, and finding the root causes (Ballard and Howell, 1994). Measuring PPC allows differentiating between failures to complete plans and failures in plan quality (Ballard and Howell, 1994). According to a survey conducted by lean construction institute for local and international companies, 79% considered PPC as an important indicator of project progress (Hamzeh, 2009). However, focusing on PPC alone can be misleading because projects might have high PPC but are late, it occurs when the activities that were performed are not critical or out of sequence (Hamzeh, 2009). Thus, definition, soundness, and sequence of weekly activities must be considered in the course of evaluating project PPC.

Although there are many reports written about UN funded projects, yet there are no case studies related to project performance or LPS implementation. United Nations funded construction projects are considered one of the hardest projects for implementing LPS. This is due to the fact that the UN system follows very systematic rigid policies that rarely seek change. Typically, the UN performs project evaluation through temporary consultants, but none of their work is published. Unfortunately, these evaluation reports are archived and not shared with other organizations. Therefore, making any possible improvement to the project becomes a difficult task. This is the case with UN funded shelter rehabilitation project in Lebanon.

SHELTER REHABILITATION PROJECT

According to the latest field survey by United Nations Relief Works Agency (UNRWA) in Lebanon there are 4,127 shelters inside Palestinian refugee camps that require rehabilitation (UNRWA, 2011). These camps as shown in figure 2 are known for their tight alleyways, unorganized urban planning, and lack of proper infrastructure.

Figure 2 - Camp infrastructure, tight alleyways

Rehabilitation projects inside the camps are one of the biggest challenges facing UNRWA. In a traditional contractual approach, shelter unit cost is high due to refugee camps harsh conditions.

Upon the request of some families to perform the construction work themselves, a new approach was implemented called Self-Help. In Self-Help, the families act as owners and contractors during rehabilitation. Self-help methodology proved to be a better and cheaper alternative to the old contractual approach saving approximately 50% in cost (SDC, 2010; Eljazzar, Beydoun and Hamzeh, 2013). This approach was implemented previously by Norwegian Refugee Council NRC in Balkans, and western Georgia. The cost savings ranged from 20% to 40 % (NRC, 2010).This approach encourages families to take responsibility, learn new trades, and manage the development of their own shelter (SDC, 2010).

In order to standardize the rehabilitation project, UNRWA created a set of guidelines that dictate the level of intervention, number of rooms, cost, and duration of work for each shelter. For example, a family composed of three to four members will be entitled to rehabilitation of two rooms in addition to the kitchen and the toilet. Therefore, the number of rooms included in rehabilitation is a function of family members. Moreover, the cost for each shelter is divided into instalments; each instalment will be paid upon fulfilling a set of activities. Payment order will be sent upon the approval of UNRWA’s site engineers supervising the shelter. This allows the family to collect the payment after six to twelve working days. UNRWA rehabilitation works can be divided as follows:

- **Minor repair**: includes minor repair works, such as paint, minor electrical and plumbing works.

- **Major repair**: includes block work, plaster, paint, Tiling, major plumbing and electrical works.
- **Partial reconstruction**: includes concrete works , in addition to block work ,plaster, paint ,Tiling, plumbing , major plumbing and electrical works
- **Reconstruction**: rebuilding the whole shelter completely.

To assess the shelter rehabilitation project a sample of ten houses will be monitored, PPC will be measured, and the causes of delay will be recorded. The on-going research aims to pave the way for implementing LPS in UN environment.

METHODOLOGY

This study analyses data collected from a sample of ten shelters undergoing rehabilitation over a period of four weeks. Two weekly visits were conducted for each shelter: one at the beginning of the week to record the planned tasks, and one at the end of the week to record the delivered tasks along with causes of delay. In this project Percent Plan Complete (PPC) wasn't used by UNRWA or families it was running in the background. After looking at the project and visiting the sites, PPC was the only metric to measure the weekly performance of the projects. To ensure that PPC reflected the facts on the ground, activity overloading and under-loading was monitored, as well as the sequence of activities. In this sample, such incidents did not occur.

The shelters under study were chosen from two different refugee camps located in Beirut. In order to establish a comparison benchmark, the houses were chosen based on rehabilitation type while taking into consideration the number of rooms and the total area. Three factors were considered in the study, the width of the paths connecting the shelter with main access roads, the location of nearby construction sites, and continuous supervision by family members. Finally, some interviews with field engineers were performed in order to check the soundness and the sequence of performed tasks.

SHELTER DESCRIPTION

In order to establish a comparison criterion, the characteristics of several shelters were recorded. These characteristics are presented in Table 1. Shelters (SHs) entitled for major repair were chosen to be composed of two rooms, a kitchen, and a bathroom. The SHs areas range from 43m2 to 58 m2.In SH 1 and 10 the families hired a contractor to carry out rehabilitation works, while others hired different tradesmen. In SH 1, 9, and 10 the families did not participate nor supervise the rehabilitation works while the rest did. Only in SH 4 the family supervised but didn't participate in the rehabilitation works. SH 1 and 3 suffered from difficulty in entering material due to congestion from nearby construction sites; while SH 4, 6and 7 suffered from tight alleyways that connect them to main access roads.

Table 1 - Shelter Detailed Information

Shelter	Area(m2)	Paths to main road tight	Nearby construct ion sites	Rehabilitation approach	Regular supervision	Participation in Rehab. works
SH 1	43	×		Contractor	No	No
SH 2	44.5			Diff. tradesmen	Yes	Yes
SH 3	48.3	×		Diff. tradesmen	Yes	Yes
SH 4	55.5		×	Diff. tradesmen	Yes	No
SH 5	48.7			Diff. tradesmen	Yes	Yes
SH 6	52		×	Diff. tradesmen	Yes	Yes
SH 7	58		×	Diff. tradesmen	Yes	Yes
SH 8	51			Diff. tradesmen	Yes	Yes
SH 9	45.8			Diff tradesmen	No	No
SH 10	53.8			Contractor	No	No

RESULTS

During the project duration, several parameters were recorded; the average PPC, the status of work, and the reasons for any incomplete activities. Table 2 below shows the average PPC, and the status of each shelter at the end of the project duration. SH 1, 9, and 10 had an average PPC between 42% and 50%, and they were delayed. SH 2, 3, 4, 5, 6, 7, and 8 had an average PPC between 80% and 86%; and they were completed.

Table 2- Shelter average PPC and status

Shelter	Avg.PPC	Status
SH 1	42	Delayed
SH 2	80	Completed
SH 3	83	Completed
SH 4	80	Completed
SH 5	84	Completed
SH 6	83	Completed
SH 7	82	Completed
SH 8	86	Completed
SH 9	42	Delayed
SH 10	50	Delayed

The reasons for incomplete weekly activities within these projects can be divided into two categories; reasons that are within family/contractor control and those that are not within their control. Reasons such as manpower, rework, inaccurate duration estimate, prerequisite work not ready, litigation and lack of know how are within family/contractor control. Others reasons such as funds and unexpected site conditions are not under family/contractor control. Figure 3 shows that the major contributors for incomplete weekly task are funds (delay in payments), unexpected site conditions, manpower, and rework with percentages varying from 26%, 16%, 15%, and 15% respectively.

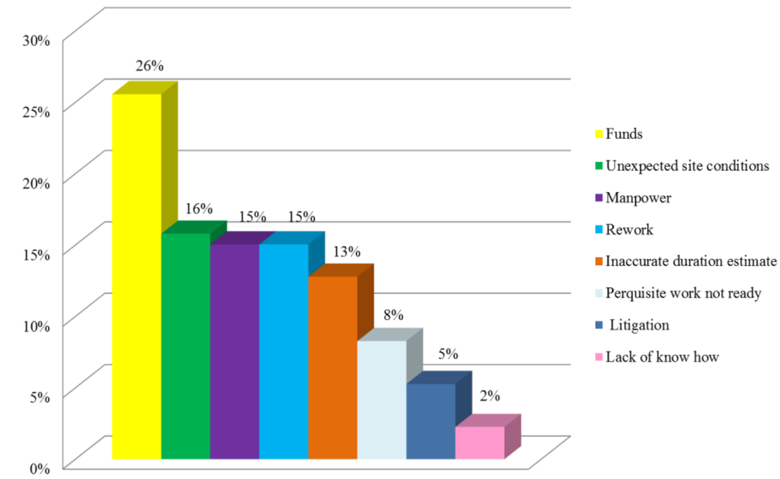

Figure 3: Reasons for Incomplete weekly

DISCUSSION

Figure 4 shows PPC curves for all the shelters during project duration along with the average PPC . It can be clearly seen that SH 2, 3, 4, 5, 6, 7, and 8 that finished on time are above the avergae PPC curve, whereas SH 1, 9, and 10 that were delayed are below the trendline.

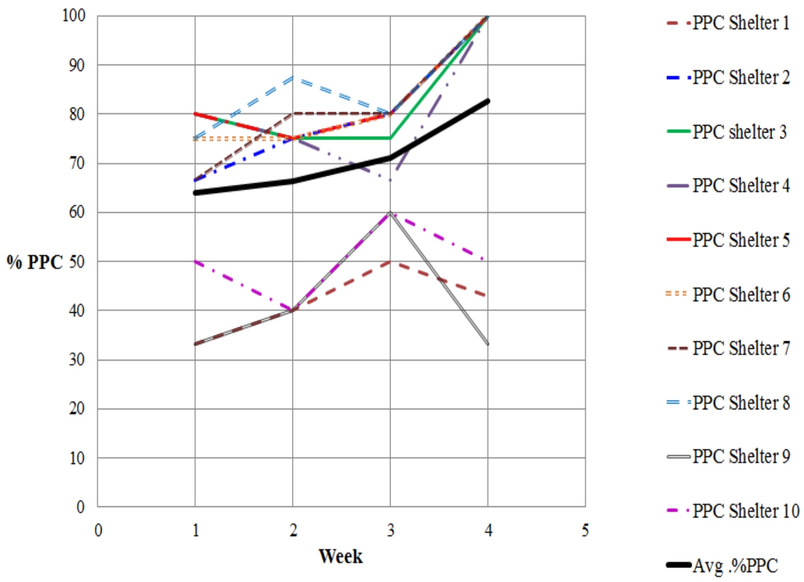

Figure 4: %PPC variation for all shelters

In delayed shelter, the workflow was slow and unorganized. The families in SH 1, 9, and 10 didn’t supervise nor participate in activities; this resulted in poor execution of the tasks. In SH 1, and 9 the head of the family is very old; thus the younger members supervised the work in non-regular manner. Therefore, no one was taking an effective role on organizing work on site. Moreover, the hired contractor tried to keep the number of workers to a minimum to ensure maximum profit. Rework, lack of manpower, inaccurate duration estimates were common reasons for delay in these shelters. In SH 10 the contractor was a relative to the family, they trusted him to perform the tasks; unfortunately, due to lack of follow up the quality of work was poor. The field engineer supervising the shelters refused the performed tasks multiple times, and forced them to redo the work. In summary, the families failed to actively engage and supervise the works.

In completed shelters, the workflow was fast and organized compared to delayed shelters. Some families hired tradesmen, others hired contractors; however , family members performed some rehabilitation activities, such as demolishing, plastering, painting, and transporting construction materials to site. The families managed the site and supervised the works in an agile manner. For example, SH 4, 6, and 7 had difficulty in transporting and handling material due congestion caused by neighbouring construction sites; to overcome this they transported the material at night time. Furthermore, the families continuously improved the activities. For example in SH 6 and 7 the families forced the workers to redo some of the tasks when they noticed poor implementation. In addition, in SH 8, the family noticed that internal plastering team productivity was low; as a result, they changed the team, and they hired another one for external plastering thus ensuring a parallel work flow for external and internal work activities. Moreover, in SH 3, workers had to use staircase to deliver backfill material from main access road to the shelter. After the material was dumped on the side of the main access road, it was filled in small bags that were then transported by workers back and forth on a long staircase. The family noticed that the old delivery method was time consuming, and it caused fatigue among the workers. To deal with the material delivery issue, 12 inch PVC pipe was used. The pipe was placed in a slopped manner spanning from main access road to the shelter as shown in Figure 5.Thus, ensuring a fast delivery method for backfill material.

Figure 5: Backfill material delivery

Finally, in SH 4, 5, and 6 the families prepared the site before the notice to proceed from UNRWA. They cleared the furniture from the house. They evacuated the house and started demolishing works for walls mentioned in contract. Hence, they gained an additional week. In summary, the families showed a great deal of collaboration. They expedited the flow of work through consistent supervision, and continuous improvement. The families showed lean behaviour during work; they tested different scenarios, removed constraints, took the initiative, and implemented the work safely.

One of the major contributors for incomplete weekly tasks was the delay in receiving funds which caused major disruption for work flow.

Each family in this project was given a scope of work schedule, including the activities that must be completed in weeks and the payments that will be received upon satisfactory completion. Failing to achieve the progress required in the scope of work - can be seen by low PPC scores - resulted in delayed payments request which add up to payments processing duration which ranges from six to twelve weeks. For shelters with high PPC, families were working ahead of schedule achieving more tasks faster. Thus, payment processing duration should be faster to accommodate for both delayed and fast shelters.

Refugee camps are dynamic environments and conditions vary every hour. Unexpected site conditions cannot be handled in planning. However, all families suffered equally from these conditions. Families that were present on site with contractors, managed to remove these conditions and solve them on site compared to other families that solely depended on foreign contractors who do not know the camp. Looking at Table-1, SH 9, and SH 10 didn’t suffer from unexpected site conditions, however they were delayed. SH 3 to SH 8 managed to fix these conditions and achieve a higher PPC. In camps electrical and water lines are running together externally in a web form directly on top of the streets as shown in figure 2. During rehabilitation, some alleyways couldn’t be accessed due to leakage in water pipes which resulted in electric hazards. According to UNRWA’s field engineers and families, many refugees have lost their lives due to lack of proper infrastructure.

In the self-help approach regular supervision is a must. Even though UNRWA’s field engineers visit every shelter on daily basis, some families worked at night time when engineers weren’t on site. The role of the families is to fill the supervision gap and organize the flow of work in order to help achieving the rehabilitation process. Failing to supervise the works, will result in poor implementation of tasks as seen in SH 1, 9, and 10.

CONCLUSIONS AND FURTHER STUDIES

This study monitored ten shelters in a UN funded rehabilitation project in Palestinian refugee camps applying the self-help approach. PPC and causes for incomplete tasks were measured and analyzed for the projects’ duration of 4 weeks. In order to establish a comparison, the houses having similar characteristics such as area, type of repair, and access to main road were chosen. PPC wasn’t used by families or UNRWA to do weekly plans; instead it was running in the background.

The results showed that SH 1, 9, and 10 were delayed with average PPC between 42% and 50%. The poor performance was due to lack of regular supervision during project. On the other hand, SH 2, 3, 4,5,6,7, and 8 were completed with average PPC between 80% and 86%. The families took advantage of the rehabilitation process. They were Lean in managing the site, followed up all aspects of work, continuously improved processes, and removed constraints (Hamzeh and El Jazzar, 2015). The main motivator was the fact many families lived in extremely poor conditions for a long time, thus living in a decent and safe shelter is a once in a lifetime opportunity for them. When they were given the chance to repair their shelters through self-help approach, they worked very hard to achieve the best results, hence projecting their attachment to their homes through extreme effort. Still delay in receiving funds, and unexpected site conditions were the major contributors for incomplete weekly tasks in all shelters with an occurrence rate of 26% and 16 % respectively. Delay in transferring funds is caused by the bank transfer process. Unexpected site conditions are caused by the camps unorganized infrastructure.

This study shows the benefits of Self-Help approach and how it affects families' lives. This process promotes lean behaviour as it engages people in the repair process, driving them to take initiative, and achieve their dreams. Even though this method wasn't designed to be lean, yet for this specific project there was a high correlation between both (Hamzeh and El Jazzar, 2015).This study measures LPS metric, and causes of delay which is the first time in a UN funded project. Project evaluations that was previously done, didn't measure field data such as PPC. The aim is to promote further research in order to implement LPS in UN projects as these projects affect people life's directly. Future research should focus on improving the fund transfer process, and studying more complex interventions such as reconstruction since these interventions hold more challenges along the way. In addition, Self-Help method in the scope of this particular project promoted lean behaviour (Hamzeh and El Jazzar, 2015). However, applying self-help on other types of projects requires further research.

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IDENTIFICATION OF REPETITIVE PROCESSES AT STEADY- AND UNSTEADY-STATE: TRANSFER FUNCTION

Ricardo Antunes[1], Vicente A. González[2], and Kenneth Walsh[3]

ABSTRACT

Projects are finite terminating endeavors with distinctive outcomes, usually, occurring under transient conditions. Nevertheless, most estimation, planning, and scheduling approaches overlook the dynamics of project-based systems in construction. These approaches underestimate the influence of process repetitiveness, the variation of learning curves and the conservation of processes' properties. So far, estimation and modeling approaches have enabled a comprehensive understanding of repetitive processes in projects at steady-state. However, there has been little research to understand and develop an integrated and explicit representation of the dynamics of these processes in either transient, steady or unsteady conditions. This study evaluates the transfer function in its capability of simultaneously identifying and representing the production behavior of repetitive processes in different state conditions. The sample data for this research comes from the construction of an offshore oil well and describes the performance of a particular process by considering the inputs necessary to produce the outputs. The result is a concise mathematical model that satisfactorily reproduces the process' behavior. Identifying suitable modeling methods, which accurately represent the dynamic conditions of production in repetitive processes, may provide more robust means to plan and control construction projects based on a mathematically driven production theory.

KEYWORDS

Production, process, system identification, transfer function, system model, theory;

INTRODUCTION

Construction management practices often lack the appropriate level of ability to handle uncertainty and complexity (McCray and Purvis, 2002; Abdelhamid, 2004) involved in project-based systems resulting in projects failures in terms of projects schedule and budget performance, among other measures (Mills, 2001). Traditional scheduling approaches in construction, such as critical path method, have been

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unrestrictedly used producing unfinished and erratic plans (Abdelhamid, 2004; Bertelsen, 2003a) consequently creating distrust, and often being abandoned by those conducting project work. Even more recent scheduling approaches, such as the ones based on the line-of-balance method, assume that the production in construction operates at steady-state with constant production rates (Lumsden, 1968; Arditi, et al., 2001), where any deviation is understood as variability (Poshdar, et al., 2014). However, "the assumption that production rates of construction projects and processes are linear may be erroneous" (Lutz and Hijazi, 1993). Production throughput is highly variable in construction projects (Gonzalez, Alarcon and Molenaar, 2009), has transients (Lutz and Hijazi, 1993), occasionally is at unsteady-state (Bernold, 1989; Walsh, et al., 2007) and frequently is nonlinear (Bertelsen, 2003b). As such, approaches that depend on constant production rates, *i.e.*, a steady system, possibly produce erroneous and imprecise outcomes.

The dynamics of the production system in construction is frequently overlooked (Bertelsen, 2003b), and the transient phase is ignored (Lutz and Hijazi, 1993). The general construction management makes no distinction between the production dynamics and disturbance, considering both as variability (Poshdar, et al., 2014). However, dynamics, disturbance, and variability have different meanings and action approaches. The dynamics is an essential characteristic of any process, representing the effects of the interaction of components in a system. Process dynamics should be understood, managed and optimized. External factors cause disturbance, which must be filtered, mitigated and avoided consequently reducing any impact on the process, *e.g.*, risk management (Antunes and Gonzalez, 2015). The understanding of these concepts is fundamental to the development of mathematical relations and laws suitable to the construction production system. At this time, construction adopts the manufacturing model, dismissing the application of mathematical approaches to model and manage its production system (Laufer, 1997; McCray and Purvis, 2002; Bertelsen, 2003a).

Although much work has been done to date on production estimates of repetitive processes, more studies need to be conducted to understand and develop the dynamics of these processes. The purpose of this study is to evaluate the transfer function in its capability of identifying and describing the dynamics of project-driven systems in repetitive processes in construction. This topic was identified as being of importance to point out a unique mathematical representation of project-based systems process in transient, unsteady-, and steady-state, furthermore, overcoming a major limitation of fixed production rates estimation approaches. The understanding of project dynamics should improve estimation accuracy approaches and support suitable derivations of manufacturing management practices in order to increase productivity in construction projects. This study is a step towards the development of a mathematically driven production theory for construction.

A SYSTEM VIEW

Mathematical models have enabled a comprehensive understanding of production mechanisms supporting practices to improve production in manufacturing. Hopp and Spearman (1996) committed to the comprehension of the manufacturing production system. The system approach or system analysis was the problem-solving methodology of choice (Hopp and Spearman, 1996). The first step of this methodology is a system view. In the system view, the problem is observed as a system established by a set of subsystems that interact with each other. Using the system approach, Hopp and Spearman elaborated significant laws to queue systems and the general production in manufacturing. The conservation of material and capacity laws (Hopp and Spearman, 1996) are particularly attractive, not only according to their importance, but also because they explicitly state one or more system restrictions. These laws place reliance on stable systems, with long runs and at steady-state conditions. However, production in project-based systems, such as construction, involves a mix of processes in steady- and unsteady-state, short and long production runs, and different learning curves (Antunes and Gonzalez, 2015). Hence, unless a construction process fulfills the stability and steady-state conditions, the manufacturing model and, consequently, the laws do not accurately represent production in construction. Alternatively, variants of manufacturing laws must be developed to production in project-based systems that not fulfill those requirements. In this scenario of variety, it is crucial distinguishing between project-based systems conditions, comprehending process dynamics and its behavior.

SYSTEM IDENTIFICATION

The objective of system identification is to build mathematical models of dynamic systems using measured data from a system (Ljung, 1998). There are several system identification approaches to model different systems, for instance, transfer function. The transfer function is particularly useful because it provides an algebraic description of a system as well means to calculate parameters of the system dynamics and stability. Nevertheless, the modeling capability of the transfer function in construction must be evaluated and tested. In this study, the modeling approach, *i.e.*, transfer function, focuses on replicating the input/output “mapping” observed in a sample data. When the primary goal is the most accurate replication of data, regardless of the mathematical model structure, a black-box modeling approach is useful. Additionally, black-box modeling supports a variety of models (Bapat, 2011; Billings, 2013), which have traditionally been practical for representing dynamic systems. It means that at the end of the modeling, a mathematical description represents the actual process performance rather than a structure biased by assumptions and restrictions. Black-box modeling is a trial-and-error method, where parameters of various models are estimated, and the output from those models is compared to the results with the opportunity for further refinement. The resulting models vary in complexity depending on the flexibility needed to account for both the dynamics and any disturbance in the data. The transfer function is used in order to show the system dynamics explicitly.

TRANSFER FUNCTION

The transfer function of a system, G, is a transformation from an input function into an output function, capable of describing an output (or multiple outputs) by an input (or multiple inputs) change, $y(t) = G(t) \star u(t)$. Although generic, the application of the transfer function concept is restricted to systems that are represented by ordinary differential equations (Mandal, 2006). Ordinary differential equations can represent most dynamic systems in its entirety or at least in determined operational regions producing accurate results (Altmannand Macdonald, 2005; Mandal, 2006). As a consequence, the transfer function modeling is extensively applied in the analysis and design of systems (Ogata, 2010). A generic transfer function makes possible representing the system dynamics by algebraic equations in the frequency domain, *s*. In the frequency domain, the convolution operation transforms into an algebraic multiplication in *s*, which is simpler to manipulate. Mathematically, "the transfer function of a linear system is defined as the ratio of the Laplace transform of the output, *y*(*t*), to the Laplace transform of the input, *u*(*t*), under the assumption that all initial conditions are zero" (Mandal, 2006), Equation 1. Where the highest power of *s* in the denominator of the transfer function is equal to *n*, the system is called a*n*th-order system.

$$G(s) = \frac{\mathcal{L}\left[u(t)\right]}{\mathcal{L}\left[y(t)\right]} = \frac{U(s)}{Y(s)}$$

Equation 1: Transfer function

TRANSIENT STATE, STEADY-STATE, AND UNSTEADY-STATE RESPONSE

Two parts compose a system response in the time domain, transient, and steady- or unsteady-state. Transient is the immediate system response to an input from an equilibrium state. After the transient state, a system response can assume a steady- or unsteady-state. In a stable system, the output tends to a constant value when $t \to \infty$ (Mandal, 2006). When the system response enters and stays in the threshold around the constant value the system reached the steady-state (Mandal, 2006). The time the stable system takes to reach the steady-state is the settling time, t_s. On the other hand, if the response never reaches a final value or oscillates surpassing the threshold when $t \to \infty$ the system is then at unsteady-state. Consequently, the system outputs at unsteady-state vary with time during the on-time interval even induced by an invariable input.

METHODOLOGY

A sample of 395 meters of continuous drilling was randomly selected from the project of an offshore oil well construction, constituting the process to be modeled. The information containing the drill ahead goal and the current process duration was collected from operational reports and resampled to 181 samples representing the hourly process behavior when commanded by the input, establishing a system. Next, the estimation of a transfer function was used for the determination of a model that represents the dynamics of the system-based process. The estimation uses nine partitions of the dataset creating models based on different data sizes. The best model from each of the nine partitions presenting the lowest estimation unfitness value were selected and cross-validated by the remaining data. Later, the system response of the best model was analyzed.

CASE STUDY: DRILLING AS A SYSTEM

The subject of this study is the drilling process on a particular offshore well construction project in Brazilian pre-salt. This process was chosen given its high level of repetitiveness. The vertical dimension of repetitiveness is the repetition of the process in the project, *i.e.*, the drilling occurs more than one time in the construction of a well. The horizontal dimension is the repetition of the process in different projects, *i.e.*, the drilling occurs on every well construction project. Such degree of repetitiveness eases comparison and data validation because a repetitive process tends to present patterns in smaller data portions. The case documentation provides details about inputs, outputs and brief explanations of the process parameters. Nonetheless, the documentation does not include any mathematical representation of the processes other than the drilling parameters and other activities performed while drilling, which constitute subsystems. For instance, the work instructions to drill a segment of 28 meters on seabed:

- Drill ahead 8 1/2" hole from 3684 m to 3712 m with 480 gpm, 1850 psi, 15-25k WOB, 120 rpm, 15-20 kft.lbs torq. Perform surveys and downlinks as per directional driller instructions. Pump 15 bbl fine pill and 50 bbl hi-vis pill every two stand as per mud engineer instructions.

The primary input, 'drill ahead from 3684 m to 3712 m', and the parameters, such as torque and rpm, directly affect the drilling process. However, the system view unifies the different parts of the system, *i.e.*, the subsystems, into an effectual unit using a holistic perspective. The holistic perspective allows the creation of a system driven by a primary input while all others variables interact as subsystems of the main system.

To fully establish a system, an input has to be applied to the process in order produce an output. Accordingly, the input, $u(t)$, consists of a drilling ahead depth goal, *e.g.*, 3712 meters, that is applied to the drilling process, producing the output, $y(t)$, that is the actual depth, in meters. In the process, $G(t)$, the drilling crew responds to the drilling ahead goal by drilling and performing related tasks, which increases the actual well depth over time until reaching the drilling depth goal. Then, a new drill ahead goal is set, and the process performs the cycle. The sample data corresponds with a well depth increase from 3305 to 3700 meters at a variable rate based on operational choices. The 181 samples represent the hourly input and process behavior response, *i.e.*, output. The input and output data are cumulative due to physical restrictions. In other words, it is impossible to drill from 3435 meters without prior drilling from the seabed at 924 meters from water level to 3435 meters in the hole. Consequently the drill ahead goal as well as the actual depth values are always greater than the previous values. Figure 1 displays the general system representation of the process with its measured input and output, drill ahead goal and actual depth respectively. Two criteria guided the choice of drilling goal as input. The first criterion is that the drill ahead goal is the primarily directive to achieve the objective of the project, setting the peace to build the well. The drill ahead goal is an adaptive plan in which the team has to examine the current conditions of the well and determine the best drill ahead goal. It relies on guidelines and procedures but in the end its a human decision. The second criterionis that this particular arrangement illustrates the number of items arriving in a queuing system at time t. Additionally, the output represents the number of items departing in the queuing system at time t. Such input-output arrangement is instrumental to adapt manufacturing-based models such as the Little's Law (Little, 1961) to construction in further research.

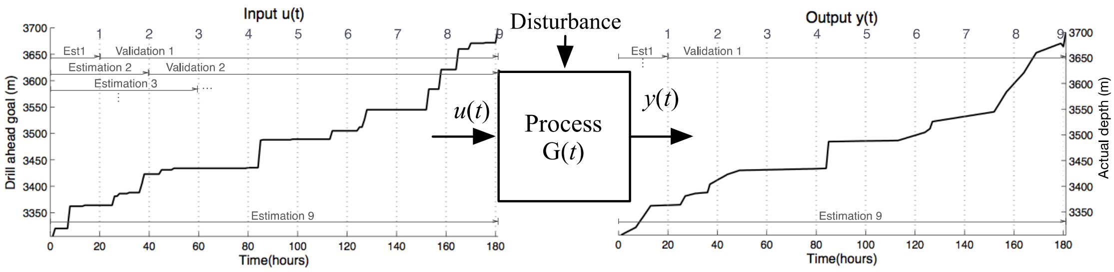

Figure 1. System representation of the case study

INITIAL MODELING APPROACH

A simple model is attempted initially before progressing to more complex structures until reaching the required model accuracy. Simpler models are easier to interpret, a desired feature in this study. However, if that model unsatisfactorily simulates the measured data, it may be necessary to use more complex models. The simpler system identification approach is the transfer function. Hence, transfer function might be a good starting point in order to identify, model and understand the behavior of a system. The sample data was partitioned in nine combinations representing nine stages in time, as shown in Figure 1. The first partition is at the 20th hour. Therefore, the data from zero to 20 hours was used as estimation data for G_1, and from 21 to 181 hours as the validation data. The second partition happens at 40 hours mark. In the same way, the estimation for G_2 is composed of the data from zero to 40 hours mark, and the validation is from the 41st to the 181st hour. This pattern repeats until the 180-time stamp. At this partition, almost the whole sample constitutes the estimation data, and only one sample is left for validation of G_9. The model from this partition, G_9, merely fits the estimation data once there is virtually no data that could be used to validate the model. Based on black-box trial-and-error approach, the model parameters of the transfer function of first-order (Ogata, 2010) were generated for each partition using the iterative prediction-error minimization algorithm (Ljung, 2010) from MATLAB’s System Identification Toolbox. A first-order transfer function eases the model interpretability.

MODEL DEVELOPMENT

Three transfer functions, which showed the lowest unfitness values, calculated by 100% – normalized root mean square (NRMSE) (Armstrong and Collopy, 1992; Ljung, 2010), were selected for each of the nine data partitions, constituting the best models. A perfect fit corresponds to zero meaning that the simulated or predicted model output is exactly the same as the measured data.

MODEL QUALITY ASSESSMENT

The initial models were later refined using the prediction-error minimization algorithm (Ljung, 1998). After refinement, the models that achieved the lowest unfitness values to each estimation data partition that they derived from were then validated using the remaining data of their partition. Figure 2 shows the quality measurements of the best models for each partition. The quality measurements are the percentage of validation and estimation data unfitness, Akaike's Final Prediction Error (FPE) (Jones, 1975), loss function (Berger, 1985) and mean squared normalized error performance function (MSE) (Poli and Cirillo, 1993). The quality measurements are represented in the graph by ‘Val unfit’, ‘Est unfit’, FPE, ‘Loss Fcn’, and MSE respectively. Although, the model choice in this study is not mathematically based on FPE, loss function and MSE their values were calculated and shown providing an extra measurement of model quality. A variety of measurements is useful for comparing different models as well as comparing the models with different modeling approaches. Differently from the models one to seven, the models for the segments eight and nine present high unfit levels to their validation segments, 72,64% and impossible to calculate, respectively. For G_8, the input-output relation of the validation data, shown in the segment eight to nine in Figure 2, is extremely distinct from the data used in the estimation, segment one to eight. For G_9, there is only one sample remaining to validate the model. Hence, the model $G_9(s) = 0.6646 / (s + 0.6687)$ corresponds to the structure that better reproduces the sample data with about 93% fitness. Accordingly, G_9 is used later to demonstrated the step response.

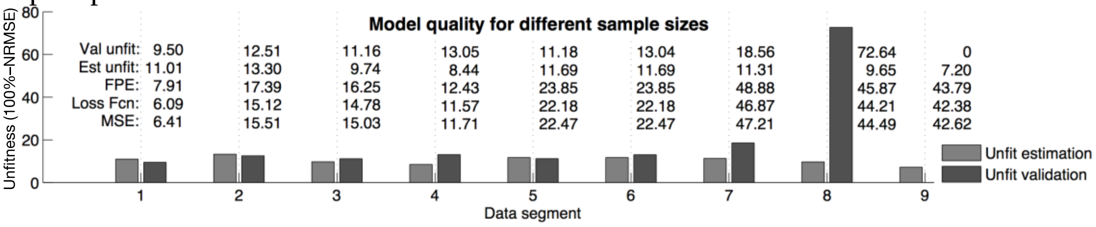

Figure 2. Quality comparison of the models

Despite the model G_9 has the lowest unfitted data, ‘Est unfit’, almost the whole sample data was used to estimateG_9. Hence, G_9 already ‘knows’the data sample and for this reason cannot be used as a predictor. In order to illustrate the prediction accuracy of the models, the model with the largest ‘unknown’ data, *i.e.*, G_1 is used. Figure 3 shows the comparison of the measured data and model $G_1(t)$, result of inverse Laplace Transform of$G_1(s) = 0.4193 / (s + 0.4103)$;the solid line is the measured output and the dashed line the model response with 9.5% unfitness. The transfer function $G_1(t)$, can represent the process input-output relationship with sufficient precision. Furthermore, the model is estimated at an early stage, around the initial 10% duration, independently of any previous process knowledge.

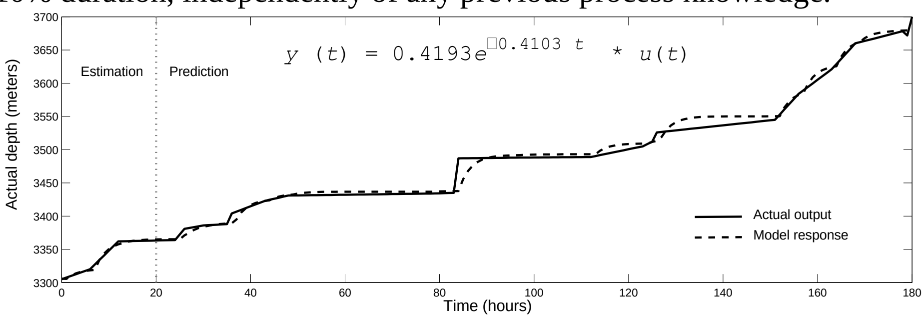

Figure 3. Comparison between the G_1 response and measured data

STEP RESPONSE

Figure 4(a) shows the step response for the model G_9. The model reaches steady-state about the sixth hour for a threshold of absolute two percent about the final value. The step amplitude used as input, 2.06, is the average drilling goal ahead. The system responds to this input reaching and staying steady at the output peak, $y_p = 2.05$, about the 16th hour, t_p. In this case, the steady-state value is the peak value because it is the value that the system tends to when $t \rightarrow \infty$ (Mandal, 2006). The average drilling rate from the measured output data is 2.1 meters per hour approximately the model output at steady-state, with a three percent error. Consequently, the model represents the system at steady-state. Although, the transient response stands for a significant part of the system dynamics. The system has a transient response every time it starts or stops. Although it stays at the transient state when it need small corrections, as, for instance, to fit a casing pipe to secure the well. In this case, the system also has inputs as small as one. For this input, the average response of the system is 0.55 meters per hour. In order to assess the system transient response, a unitary step unit was introduced to the system producing the system response, as shown in Figure 4(b). The average response for the unitary input is achieved around one hour by the system indicating that the system is performing in the transient state.

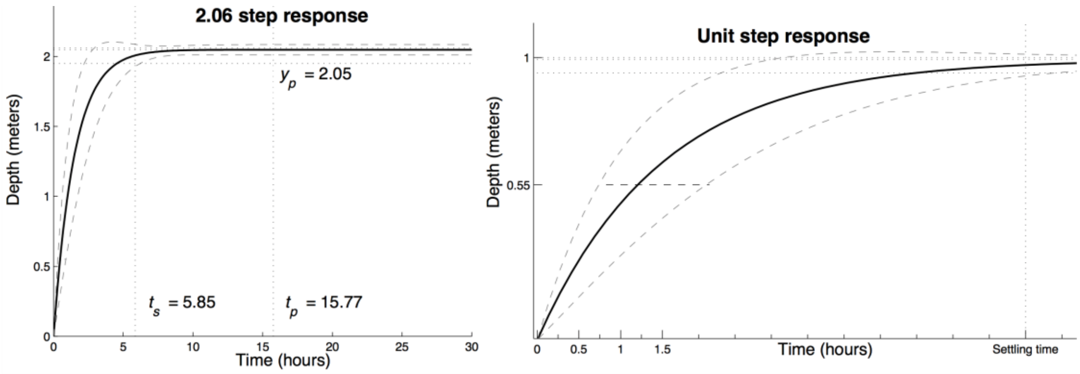

Figure 4. (a) 2.06 step response (b) Unit step response

CONCLUSIONS

The results of the model's accuracy were explicit. The models were consistent with the modeling approach and methodology. The valid transfer functions obtained reliablydescribed the process behavior and presented evidence of their accuracy using a range of model quality measurements. These findings thus lend support to the use of transfer function as a valid model approach and analytical technique in order to describe the dynamic conditions of production in repetitive processes in projects.

Accounting for transient responses, transfer function fulfills a gap left by network scheduling and queueing theory as well as linear and dynamic programming, which ignore the transient stage and assume that the process is at steady-state. Moreover, a transfer functions may act as a multi-level management tool. Because transfer functions provide an output function from an input function, they enable the creation of accurate plans rather than single actions and a throughput function, instead of a system position. Transfer functions may be used by site managers as a process descriptor to monitor and control low-level activities, as shown in Figure 3. Dynamic and accurate plans that respond to actual inputs can regain the trust of those conducting the project work on planning and scheduling. Moreover, the model simulation may be used in a means-ends analysis determining the best solution to a construction process, which frequently requires the optimization of resources to the detriment of shorter duration. In other words, managers may use the model adjusting the drill ahead goal plan until attaining the defined goal, supporting managers' decision-making process. Once the managers are satisfied with both the drill ahead goal plan and the system's outcome, the plan is executed. A transfer function may also be applied to represent higher levels, providing project managers a holistic view.

Reliance on this method must be tempered, however because the case does not represent the general conditions of repetitive process in construction. There is a variety of construction processes that happen in different states, production runs, and different learning curves creating unique process' characteristics. For instance, this study presents the analysis of system's transient and steady-state response, but not unsteady-state because the case scenario does not have this characteristic. Although the model can be reused in similar processes as an initial model, a limitation places on the existence of the process' input-output data. It means that the model accuracy cannot be evaluated until some data has been produced. Finally, the study explores several concepts that are unfamiliar to general construction managers at this point restricting its audience. Nevertheless, the search for and the aggregation of knowledge and expertise from different disciplines and technical fields constitutes the foremost forces driving the evolution in managerial sciences.

FUTURE OUTCOMES

Different system identification approaches can write equations for practically any process. However, only after extensive research about the dynamic conditions of production in project-driven systems the lack of knowledge about the transient and unsteady-state responses can be replaced by explanatory and mathematical laws to production in projects. In a further horizon, processes transient and unsteady-state will be understood and managed to generate an optimum process outcome. Being it reducing the transient time, and faster-moving processes to steady-state or applying unsteady-state processing techniques producing an average output above steady-state levels and then creating high-performance processes.

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DYNAMIC BENEFITS MAXIMIZATION MODEL FOR RENOVATION WORKS OF LANDED RESIDENTIAL PROPERTIES IN MALAYSIA

Christy P. Gomez[1] and Abdulazeez U. Raji[2]

ABSTRACT

In Malaysia, landed residential building design for mass housing has been influenced by the orientation towards a "seller's market, without prioritizing the changing needs of the owner-occupant. This has contributed to the growing trend of having to "remodel" homes that is currently dominated by "low-value adding practices" that are embedded within traditional benefits realization principles, amounting to brief freezing. There is a disregard for client's engagement at the construction phase, wherein the client is constrained by the practice of restrictive benefits realizations. This issue is underlined by a predominant positivist orientation to the issue of client participation that does not recognize residential housing client's ability for competency acquisition in realigning requirements to maximize benefits. This paper proposes that value maximization for such a client can best be achieved through dynamic engagement with the renovation contractor to allow for value-driven 'disruptive innovation' practice during the construction phase. Focusing on requirements capture as a process rather than an output, it is proposed that client's requirements can be realigned to maximize benefits based on a dynamic benefits realization model. This issue of benefits maximization is viewed from a social science perspective of primary stakeholder engagement within a legitimate peripheral mode of participation acting from within a community of practice whilst operating in a relational contracting environment.

KEYWORDS

Benefits realization, disruptive innovation, renovation works, relational contracting.

INTRODUCTION

In Malaysia, residential building design for landed mass housing has been influenced by the orientation towards a "seller's market; without prioritizing the changing needs of homeowners. These designs are done without any serious emphasis on future adaptability. It has led to the growing trend of having to "remodel" homes, wherein the practices are currently dominated by *low-value adding practices*. One such

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practice is the lack of consideration for client's ability to influence maximization of benefits at the construction phase of renovation works. This paper argues for an emphasis on high-value adding practices oriented towards optimizing clients benefits based on realigning requirements past the traditional post-design phase.

There is a tendency for mass terraced housing property owners (the major type of housing in Malaysia) of new property in Malaysia to undertake renovation works within a ten year period (see Raji and Gomez, 2014). In the process of undertaking renovations, additional requirements (changes) are included into the renovation works on commencement of construction. Viewed from mainstream positivist notions, these actions of active engagement at the construction phase by the client are viewed as being disruptive to existing workflow, ignoring the value enhancement component; viewing requirements capture from a singular lens. Following Rooke, et al. (2010) customer value is conceived in terms of outcomes, the effects that the outputs have on the customer. Hence, relying on the Unique Adequacy (UA) Requirements of Methods (Garfinkel, 2002) to be applied by the client for determining value, the issue of intersubjectivity of 'value' is not problematic.

The residential property homeowners undertaking renovation works can be categorized primarily as "one-off", ill-informed clients (IIC). They are further on referred to simply as ill-informed clients (IICs) who typically lack the adequate knowledge and skills (competency) to influence the architect and contractor at the outset (at the pre-construction phase) to implement alternative designs and changes to initial design. Their ability to maximize their benefits in terms spatial functionality is limited by their lack of knowledge and skills (competency) in exploratory scenario planning for benefits optimization. However, functioning in an active engagement mode with the renovation team, these IICs can develop the ability (competency acquisition in exploratory scenario planning) to contribute towards value maximization for their own ends. This is seen to be achieved primarily through acquiring increased competence to influence the realignment of requirements. Tillman, Tzortzopoulos and Formoso (2010) point out that stakeholder engagement is an important issue when considering a social science perspective to benefits realization. Hence, an interpretivist approach is taken in understanding current practice and theorizing on possibilities by critical reflection on primary experiential data as a participant-observer.

The objective of this paper is to propose a Benefits Maximization Model for renovation works of mass housing in Malaysia that can allow IICs to maximize their benefits (the aim) by focusing on the process of requirements capture. This is seen to be driven by competency acquisition by the IIC within the regime of practice of the renovation team. The epistemological basis for conceiving the potential for benefits maximization by the client during the construction phase is based on constructivist theorizing for generating value within Communities of Practice (CoPs) of the renovation project team, inclusive of the client. This is seen to take place within a relational contracting environment. Based on experiential data of the researchers, it is argued here that traditional renovation practice is restricted by four methodological constraints. In having addressed these constraints, the emphasis then needs to be refocused *towards benefits realization through the requirements capture process rather than requirements capture as a task culminating in the traditional "client's* *brief".* With reference to this context, the process of requirements capture is illustrated in Fig. 1 below, viewed from a simplified one-dimensional perspective.

RESTRICTIVE BENEFITS MAXIMIZATION

Traditionally the IICs have been constrained by non-constructivist framing of their role, placing emphasis on the contractor's perspective of achieving 'requirements capture' that is viewed as a deterministic output rather than a process. This perspective ignores the dynamics and multi-dimensionality of benefits realization from a client's perspective. Thus, disregarding the value potential of the IIC to engage with the 'renovation team community of practice'.

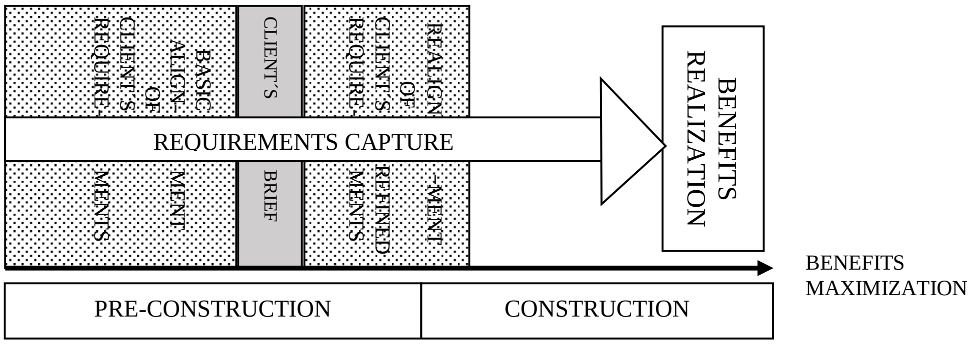

Figure 1: One dimensional perspective of requirements capture process (Dynamic Benefits Realization Model – DBRM Part 1)

It is not surprising that Reifi and Emmit (2011) note that clients have been criticized for failing to appreciate that a change request during the design stage can potentially result in a complete redesign and elevate the complexity of the production process since they generally have no understanding in the commissioning process (note that the reference is to the design stage). Such stigmas have led to a cultural predisposition of negative client engagement that has contributed to restrictive benefits realization (RBR). This is exemplified by the traditional practice of requirements capture in terms of a task culminating in the client's brief prior to the construction phase. However, by placing emphasis on the requirements capture as a process, benefits realization is seen as being externalized from tasks and related to competency leading to benefits maximization.

The notion of *RBR* within small building works (renovation works) is influenced by the low emphasis on value-based information and the lack of legitimacy accorded to client's involvement within the current requirements capture process. This paper proposes that value maximization, as benefits realization, for such a client can best be achieved through dynamic engagement in a relational sense with the renovation contractor to allow value-driven disruptive innovation on the part of the client to realize their potential benefits and realign requirements capture according to value-based information as the work proceeds. However, based on experiential data derived from two participant-observation case studies, a ball park estimate for this to happen on any one renovation project is seen to be credibly viable within 80% of work progress for any one section of work. The scope of renovation works referred to in this paper, generally involves minimal structural work and minimal standardized work.

CONSTRAINTS TO BENEFITS MAXIMIZATION

It is clear that when requirements are presented, they are rarely ready to be implemented; someone has to transform the brief into a different form of request, which can be analyzed and ultimately translated into a requirement (Kotonya and Sommerville, 1999; Wiegers, 2003). However, there can be various ways to put requirements into action that ultimately can have an influence on the value creation of the project (Lawrence, 1997; Kiviniemi, 2005).

It is noted by Sapountzis, Harris and Kagioglou (2008a) that the concept of benefits realization has been emerging in recent times as an important factor for successful programme, and additional areas of the construction process could leverage on the concept of benefits realization, including that of decision making and optioneering, performance management, impact assessment, value flow and generation, stakeholder requirements capture, change management and continuous improvement (Sapountzis, Harris and Kagioglou, 2008b).

It is noted by Garnett (1999) that, "a review of process theory and particularly, process theory in construction is [….] predominantly towards a positivist view where generic processes are sought ….." (p. 425). Additionally, in this respect, the emphasis in taking a positivist orientation, has been primarily to focus on objective outcomes in the form of 'artefacts', such as the client's brief, as a singular structured mode or mechanism for clearly identifying clients requirements; at the expense of other process based knowledge. This positivist perspective to sense-making disregards the 'growth' and 'learning' characteristic embedded within dynamic social processes such as realignment of requirements. This action of realignment of requirements is enabled by competence building capacity of the active IIC.

Additionally, even though there is evidence of research that does not limit the notion of the client's brief being cast in stone at the outset of the construction project (described earlier as mainstream practice), the issue of realigned requirements being injected into the construction phase is however not addressed. The process of refining requirements at the construction phase is often considered to be disruptive to design and work plan. This phenomena has been previously viewed within bounded rationality terms of being solely contributing to "increased costs" within the categorization of variation orders. However, this paper recognizes that in the case of renovation works, these realigned requirements tend to arise due to increased competency of IIC through engagement within an actor-network regime with existing renovation contract workers. This notion of competency as an analytical device is seen to extend existing boundaries of understanding in value maximization or benefits maximization for the client.

In terms of requirements capture, traditionally benefits realization is aimed at being secured by the client/user through the client's brief prior to the construction phase and not on a continuous basis; implying client/user participation being limited to the briefing process; a form of 'brief freezing'. Although more recent research (see, Barrett and Stanley, 1999; Blyth and Worthington, 2001; van der Voordt and van Wegen, 2005; and Jensen, 2006) has indicated that a continuous briefing process within the lifecycle of a project can yield better results, scant attention is placed on the IIC's issue of 'competency' and the ability to maximize client's benefits through their engagement within the community of practice (CoPs) of the renovation project team.

METHODOLOGY

We the researchers as human agents are seen to be engaged within the process of contributing theories to managers. In this particular instance, it is found that the practical application of the Theory of Constraints as a generative methodology for the formulation of actionable problem solving to improve processes for maximizing benefits for client's in renovation works is a valid theory to utilize. Hence, the approach has been to use the Goldratt's Theory of Constraints (TOC) to address the debilitating effect on the ability to maximize benefits for the client. The theory of constraints is a system approach based on the premise that there is at least one constraint (known as bottlenecks, delays, and barriers) in every organization that prevents the organization from utilizing its capability and capacity to achieve the organizational objectives (Goldratt, 1986). According to Goldratt (1986), the TOC approach focuses on the process of the ongoing improvement inclusive of effectively performing a series of 5 steps which are essentially involved in cause and effect thinking processes (see Figure 2).

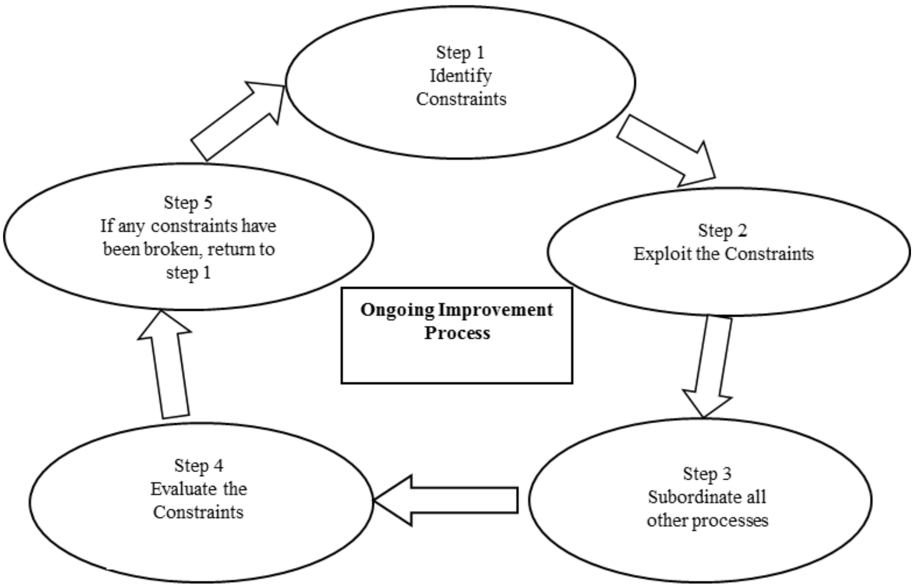

Figure 2: Five Steps of TOC Process (adapted from Goldratt, 1986)

Using Theory of Constraints (TOC) analysis alongside critical theory perspective, four basic deficiencies in renovation work practice is identified as Methodological Constraints to sense-making with regards to the issue of benefits maximization need to be addressed. They are:

- The predominant simplistic negative perception of 'variation orders' in design work that is considered to impact the project solely in terms of increased costs.

- The positivist framing of the IICs as an object devoid of innate abilities and dynamic characteristics that acts as a constraint, restricting their active engagement within the construction process.
- Disregard for taking into account the lean principle of allowing for 'design' decisions to be left to the last responsible moment right into the construction phase; thus reducing the ability to prioritize benefits maximization for the client.
- Bounded rationality perspective on client's involvement as contributing only in terms of disruptive workflow within the construction phase, limiting a broader application of value analysis.

If designs are not considered to be static, then design review of approved plans and designs for renovation should be considered as part of the process for benefits maximization; within the context of doing so at the last responsible moment. This lean principle of waste minimization and value maximization within the design process as forwarded by Tommelein, Riley and Howell (1999) is fundamental to situating this paper. It is in this context that this form of transitional disruptive workflow is seen to be a high value adding practice, overriding the predominant notion negatively viewed solely as a form of workflow disruption. Hence, the original notion of disruption accorded to client's involvement is framed here as disruptive innovation, a notion popularized by Christensen (1997).

COMPETENCY ACQUISITION BY CLIENT TOWARDS BENEFITS MAXIMIZATION

Taking the analogical reasoning as to the significant impact of the contractor's involvement in design for enhancing buildability/constructability, similarly the client is best placed to figure out his requirements through exploratory scenario planning. Although being an ill-informed client requires a certain level of competence acquisition to be able to best communicate his interests and influence the realignment of requirements within the terms of benefits maximization.

Non-value adding activities and waste is generated through the design brief due to inadequacies in brief documents (communication) and *brief freezing*. The client in a construction project is considered as integral to the design process. However, it is argued that in residential renovation works practice the client is generally viewed as an ill-informed client (IIC). The IIC is primarily operating only within a negatively perceived role as a disruptive element, hence there is no serious consideration given towards such a client's contribution that can result in benefits maximization. Traditionally, disruptive workflow is seen as a negative concept that is categorically ignored and hypothetically accorded the infamous non-value adding activity label. However, applying a basic principle of value for money (VfM), a client can decide to negotiate changes based on realignment of requirements to satisfy their need to maximize their benefits based on the lean principle of allowing for design decisions to be left to the last responsible moment. Taking the analytical perspective of "competency", the critical component that can enable the client to be acknowledged as 'member to a practice', the client is able to engage with the renovation project team at a more participative level to maximize benefits during the construction phase (See Figure 3), acting within a community of practice (CoP).

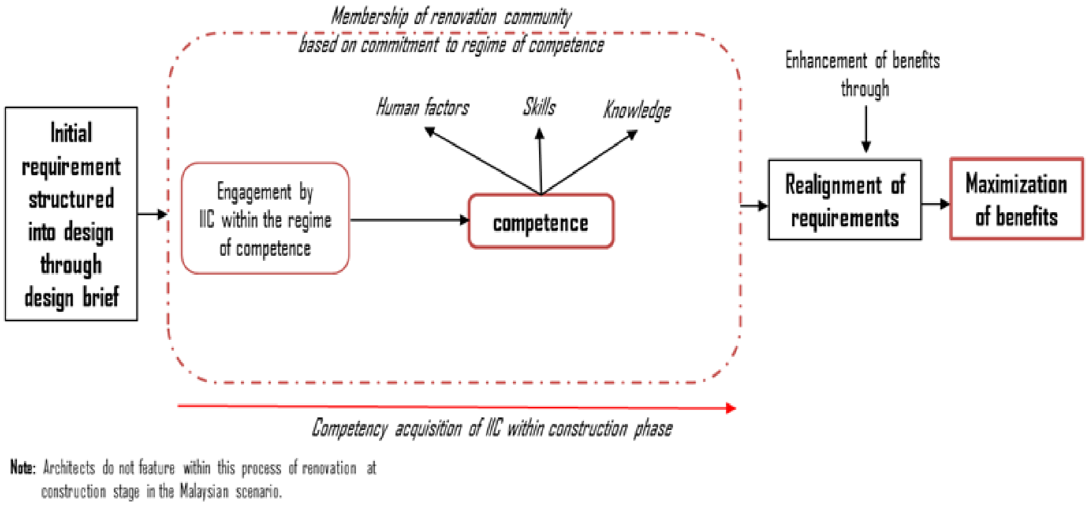

Figure 3: Competency acquisition of ICC within construction phase

COMMUNITY OF PRACTICE (COPS)

The term ‘community of practice’ was coined by Etienne Wenger and Jean Lave in the early 1990s to describe ‘a group of people who share a concern, a set of problems or a passion about a topic, and who deepen their knowledge and expertise by interacting on an ongoing basis’ (McDermott, Wenger and Snyder, 2002). CoPs are characterized by mutual learning, shared practice and joint exploration of ideas. They are distinct from other types of groups, such as project teams, working groups and social networks in that they are self-selecting, often voluntary and have fluid goals around learning rather than management objectives. They take on and spread new knowledge with a focus on implementation, rather than just theory, and can embrace an ongoing cycle of learning and doing. According to Hearn (2009) due to CoPs characterization by a community, a bound group of people, they can create trusted relationships for the exchange and practice of ideas. At their best, CoPs are naturally self-incentivizing. Members tend to stay involved and invest in CoPs due to the inherent rewards of social learning and collaboration. This also means that many CoPs emerge naturally from existing relationships and allegiances.

The notion employed here is that of Legitimate Peripheral Participation (LPP) as understood within the concept of Communities of Practice (CoP), wherein the client becomes engaged within the design considerations scenario and is seen as being accepted as a ‘member’ in terms of LPP engagement. It is through having achieved this legitimacy status that the client can then be part of the process that triggers innovative design inputs to enhance benefits maximization. This process is represented within the scope of three phases on the renovation lifecycle (see Figure 4). In this research the focus is on benefits maximization in terms of functionality of space.

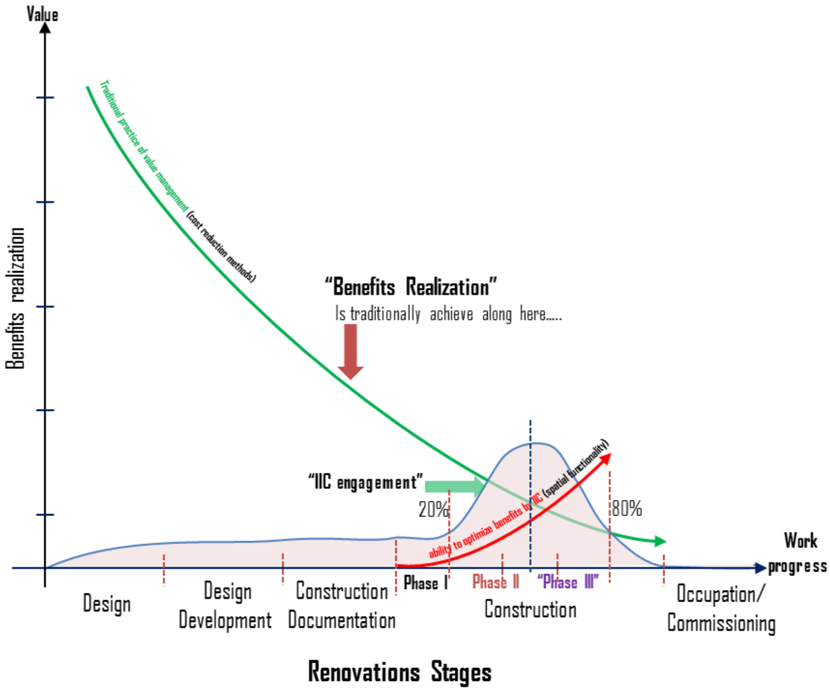

Figure 4: Benefits realization within renovation life cycle

PHASE I: MINIMUM CLIENT ENGAGEMENT

At this phase of the housing renovation works, the "one-off" ill-inform client is involved in a minimum capacity of defining his requirements. The client at this stage employs the concept of ethnographic observation trying to understand the transformation process of design leading to specific outputs and the flow of the production process. At this stage the client lacks the ability to communicate and engage with the contractor towards optimizing his benefits, whilst involved in the requirements capture process.

PHASE II: MODERATE CLIENT ENGAGEMENT

At this stage of the housing renovations works, the "one-off" ill-informed client is moderately involved in the production by testing some basic knowledge (skills) through exploratory scenario planning, acquired during the observation phase. It is conceived that at this stage the client is within the mode of Legitimate Peripheral Participation (LPP), which is the culmination of the process of gaining acceptance as a member of the renovation project team (see Lave and Wenger, 1991). The level of participation varies according to the level of recognition of the Legitimacy of the client's Peripheral Participation as accorded by the contractor's team.

PHASE III: ACTIVE CLIENT ENGAGEMENT

At this phase of the housing renovations works, the participatory "one-off" ICC client becomes better equipped with some technical skills and knowledge to be able to participate actively in the housing renovation workflow, realigning requirements capture to maximize benefits. This is a form of dynamic engagement by the ICC with the renovation contracting team to allow 'disruptive innovation', recognized within traditional workflow analysis as being disruptive. The level of participation is heightened to that of Focused Legitimate Peripheral Participation (FLPP), involving active engagement with the contractors' team (see Gomez, 2002). The ill-informed client is only then able to credibly engage in the renovations works process whilst operating within a relational contracting environment.

RELATIONAL PROJECT DELIVERY (RPD)

Matthews and Howell (2005) note that maximizing value and minimizing waste at the project level is difficult when the contractual structure inhibits coordination, they proffer that the relational contracting approach is able to align project objectives with the interests of key participants. Relational project delivery methods (RPD) have been widely proffered as a solution to maximizing holistic project value creation. Aapaoja, Haapasalo and Söderström (2013) emphasized on early stakeholder involvement as one of the foundations of RPD. Within this context the ICCs active participation is realized for further value creation during the construction phase (see Figure 5).

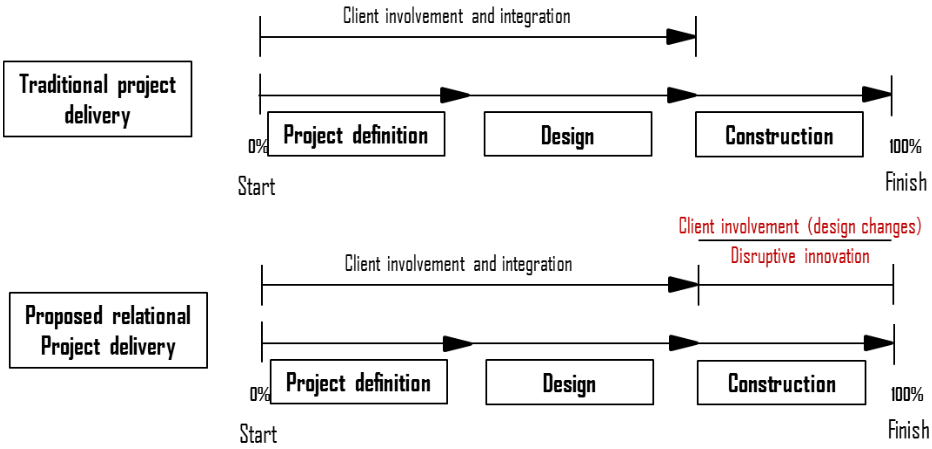

Figure 5: The difference between traditional and the proposed relational renovation projects delivery

The mainstream view is that the possibilities of influencing project success are seen to be best during the early project stages, because decisions made early reduces unnecessary changes during later development stages (Mottonen, et al., 2009). In this paper, the notion of success in renovation works is premised by benefits maximization realization (BMR) expressed in terms of value satisfaction experienced by client. This is achieved by the client participating without being confined by the traditional Four Methodological Constraints affecting renovation works. Figures 4 and 5 illustrate the scope between traditional renovation projects delivery and the proposed relational renovation projects delivery framework for benefits maximization.

COMPETENCY CONCEPTUAL FRAMEWORK FOR BENEFITS MAXIMIZATION

In using the analytical device of competency from a production science and social science perspective, a conceptual framework for benefits maximization is forwarded (see Figure 6). Wherein, the human factor variables that come under the 'social engagement' category are attributes of competency from a social science perspective. Whilst the technical skills and technical knowledge that comes under the 'production' category are attributes of competency from a production science perspective.

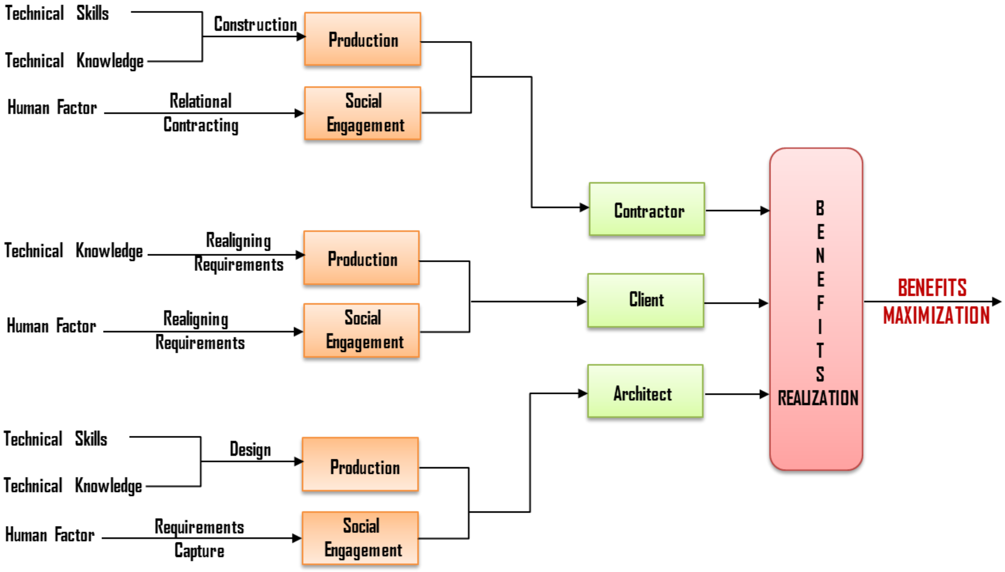

Figure 6: Competency conceptual framework for benefits maximization (Dynamic Benefits Realization Model – DBRM Part 2)

CONCLUSION

Renovation contractors currently are clearly not in the practice of allowing for benefits maximization during building renovation works process, as it is considered to be disruptive to their work flow. This notion of disruption is understood in the traditional sense of limiting changes and maintaining original work flow priority.

It is apparent that best value is not a common goal of the architect, contractor and client who are engaged in residential building renovation works. The design is done in a rather minimalistic manner, aimed at securing less problematic and commonly applied solutions from the perspective of the architect and contractor.

This paper proposes that value maximization for a "one-off", ill-informed renovation works client can best be achieved through dynamic engagement with the contracting team to allow disruptive innovation on the part of the client to realize benefits to be accrued and realign requirements capture through the proposed dynamic benefits realization model (see Fig. 1 and 6 as DBRM Part 1 and 2). Within this context, the client is seen to have the capacity to acquire competency to be actively engaged with the renovation project team in order to maximize benefits. The ill-informed client is only then able to credibly contribute to the renovation works process whilst operating within a relational contracting environment.

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TARGET VALUE DESIGN: THE CHALLENGE OF VALUE GENERATION

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ABSTRACT

Target Value Design (TVD) is a management approach that aims to maximize value in the framework of a pre-established cost target. TVD views AEC (Architecture, Engineering and Construction) as a complex system and transforms the current design practice upside down. In spite of the existing studies, applying TVD in the context of AEC still represents a major challenge. Creating a structure that enables and measures value generation to the client is part of this challenge.

However, despite the contributions already made by TVD, the results and implications related to value generation remain poorly documented. To throw light on value generation in the TVD context, it is useful to understand how the TVD and lean construction literature considers the concept of value. Thus, this study uses a literature review to understand the TVD background, as well as the main contributions made by studies carried out using this approach. The TFV (Transformation, Flow, Value) theory is considered as a baseline to understand the value generation. This paper reports a study that seeks to contribute to the challenge of adjusting the method of TVD to make value generation more explicit.

KEYWORDS

Target Value Design, target-cost, value, TFV theory, principles of value generation.

INTRODUCTION

The term Target Value Design (TVD) first appeared in a paper by Macomber, Howell and Barberio (2012) and is seen as an adaptation of Target Costing for construction industry peculiarities (Morton and Ballard, 2009; Jung, et al., 2012; Zimina, Ballard and Pasquire, 2012; Do, et al., 2014a). Target costing or 'Genka Kikaku', as originally named in Japan, is not only a tool for managing costs, but a strategic approach for the development of new products, that aims to reduce costs, ensuring quality, reliability and other attributes that will add value to the customers (Nicolini, et al., 2000; Jacomit, Granja and Picchi, 2008). In fact, Feil, Yook and Kim (2004) explain that Genka Kikaku started in Japan in the 1960s as an application of value engineering and that later this concept was translated into 'target costing'.

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In the construction context, some researchers (Denerolle, 2013; Do, et al., 2014b) emphasize that TVD started in the first successful implementation of a "designing to target cost" technique carried out by Ballard and Reiser (2004). Since then several definitions have been assigned to TVD as a management practice, method, approach or strategy: to eliminate waste and deliver value by using a 'design-to-cost' method (Kim and Lee, 2010); to keep design and cost aligned while delivering customer value by doing design-to-cost (Lee, Tommelein and Ballard, 2010); to make customer constraints drivers of design for the sake of value delivery (Ballard, 2011); to provide for integrated project delivery (IPD) through the collaborative efforts among different stakeholders (Jung, et al., 2012).

From this set of definitions, it is possible to highlight that TVD applies methods for the design to be developed in accordance with the constraints, especially cost (e.g 'design-to-cost' or 'design-to-targets'). TVD considers the customers'/clients' and stakeholders' vision to define such restrictions and deliver the required target values. Moreover, the TVD effort to keep design and costs aligned requires collaborative approaches among different stakeholders. All these efforts indicate a potential for generating value beyond cost reduction.

However, despite the contributions already made by TVD, the results and contributions related to value generation remain poorly documented. The TVD projects are mainly documented in the US and highlight the achieved cost savings but limited definition and measurement of value in the TVD projects.

To throw light on the value generation in the TVD context, it is useful to understand how the lean construction literature considers the concept of value. Thus, this study uses a literature review to understand how the studies report the contributions to value generation made by studies carried out in TVD. The usage trends of the concept of value for the lean community are considered as a baseline reference. Moreover, this study uses the five principles of the value generation cycle proposed by Koskela (2000) within the scope of TFV (Transformation, Flow, Value) as a baseline to understand value generation.

RESEARCH METHODOLOGY

The TVD papers were initially identified from IGLC conferences, the Lean Construction Journal and from websites such as Project Production Systems Laboratory P2SL Berkeley. From these papers, other conference papers, journal papers, reports and white papers were identified. The search for the papers tried to cover all papers with studies or applications on TVD, as well as papers on Target Costing as they were considered as TVD precursors or closely related to TVD.

From a sample of 30 papers identified as related to TVD, the following were documented: objectives, target value design (or target costing) definition, value concept, value expressions (value for money, customer/client values, project values, stakeholders values) and related approaches (e.g. value management, value engineering, customer requirements), client and suppliers of empirical studies, contributions, and indications for future studies.

LITERATURE REVIEW

THE VALUE CONCEPT IN THE LEAN CONSTRUCTION COMMUNITY

According to Bertelsen (2004), the work within Lean Construction has its weakest point in understanding, dealing with and managing value, which is a topic of growing importance as projects become more complex, dynamic and fast. In this sense, TFV Theory proposed by Koskela (2000) identifies three interdependent angles to production: transformation (achieved by resources workers, machines, etc.) oriented (T), materials flow oriented (F) and customer oriented (V) (Koskela, et al., 2007).

In this theory, the concept of value is approached in two different views: the value added by the transformation (inputs into outputs/products) and the value generated by the interaction between the customer/client and supplier. In both views (of value) there is the difficulty in defining and measuring value. Part of the problem is related to the complexity of the construction projects that are delivered to clients, a combination of buildings/built environments (physical attributes) and services (functionality, social context). Although this combination is usually linked to a physical product, its character is essentially intangible (Lovelock and Wright, 2002).

Considering the complex nature of the concept of value, some researchers have been faced with the need to consider the subjectivity of perception of value. Some research has sought to exploit the intangible results of the project, especially in relation to the focus on value generation and benefits. Salvatierra-Garrido, Pasquire and Miron (2012), when carrying out a literature review focusing on the use of the value concept through nineteen years of experience of the International Group for Lean Construction (conferences from 1993 to 2011), identify the following trends:

- several efforts have mainly endeavoured to examine and understand particular customer's requirements with regard to value delivery,
- some research has explored newer and broader approaches, such as benefits realisation, to understand the value generation in new projects,
- some research uses the theoretical framework from marketing.

Regarding customer requirements, some researchers advocate close involvement of the customer in the briefing, design process and project definition (Leinonen and Huovila, 2000; Emmitt, Sander and Christoffersen, 2004). The subjectivity of the perception of the value is recognized (Emmitt, Sander and Christoffersen, 2005) and the importance of the design to value generation is emphasized (Leinonen and Huovila, 2000).

Sapountzis, et al. (2010) propose the BeReal model as an approach specifically developed for the construction industry, based on the Benefits Realisation Approach from the Information Systems and Technology (IS/IT) sector. By exploring the intangible results of the project, the BeReal model moves the focus to the generation of value and benefits to different stakeholder groups involved (Tillmann, Tzortzopoulos and Formoso, 2010). According to Rooke, et al. (2010), the benefits realisation management process considers value as an issue of lean knowledge management, value being best understood as an 'intersubjective' phenomenon. In this conception, 'objective' and 'subjective', rather than being mutually exclusive categories, are more like points on a continuum in which objectivity is socially established from the stream of our perceptions (Rooke, et al., 2010).

The marketing area provides a considerable amount of research on the value concept. For instance, Hierarchical Value Maps (HVM) (Gengler, Klenosky and Mulvey, 1995) are a common output of a Means-End Chain (MEC) model, which connects the concrete attributes of a product/project (tangible attributes) with the emotional and personal values (abstract and intangible objectives) (Gutman, 1982). Considering a marketing background, Bonatto, Miron and Formoso (2011) demonstrate that a visual device, such as an HVM, can help decision makers involved in housing projects to understand the perceived value by the users. In the same way, Hentschke, et al. (2014) propose a method for defining value adding attributes in customized housing projects, which can support decision-making in project development (through the application of MEC and HVM).

THE PRINCIPLES OF VALUE GENERATION

The TFV theory (Koskela, 2000) has influenced the conceptualisation of value from current researchers and practitioners of the IGLC community (Salvatierra-Garrido, Pasquire and Miron, 2012). In this theory the cycle of value generation between the customer (client) and supplier is also related to the five principles structured by Koskela (2000).

Rooke, et al. (2010) argue that value should be treated as a problem for lean knowledge management and that all five principles require adequate management processes, as presented in Table 1. The information flows (getting information to the right people at the right time) can be traced throughout all five processes (Rooke, et al., 2010). Particularly, process 2 requirements are of flow-down (Koskela, 2000). It is argued that processes 1, 3 and 5 (requirements capture, design and evaluation) are concerned with the definition of economic value (exchange value or utility value) and that these are best seen as a continuous learning and improvement cycle (Rooke, et al., 2010). The evaluation seems to be the least explored process for which further research is recommended (Rooke, et al., 2010): long term outcomes and immediate outputs of the project, qualitative reporting and explicit methods for turning evaluation into improvement.

Table 1: The Principles of Value Generation (Koskela, 2000) and the associated Knowledge Management Process (Rooke, et al., 2010)

Principles of Value Generation	**Knowledge Management Processes**
1. ensuring that all customer requirements, both explicit and latent, have been captured;	1. to adequately discover and define customer requirements;
2. ensuring that relevant customer requirements are available in all phases of production, and that they are not lost when progressively transformed into design solutions, production plans and products;	2. to deliver knowledge of customer requirements to relevant parties throughout the production process;
3. ensuring that customer requirements have a bearing on all deliverables for all roles of the customer;	3. to transform these into an optimum design;
4. ensuring the capability of the production system to produce products as required;	4. to identify the required inputs for production;
5. ensuring by measurement that value is generated for the customer.	5. to facilitate customer evaluation and production process learning cycles.

CONSIDERATIONS ABOUT VALUE GENERATION

From the literature, some essential elements can be highlighted to be considered for value generation: the context of each project, the clear identification of the client/customer and their involvement in the project, the information (requirements) flow-down management in the design phase, the customer-supplier relationship, the evaluation cycles and knowledge management.

Notwithstanding its subjective nature, value can sometimes be subject to objective measurement, though this measurement often depends on context (Thyssen, et al., 2010). Moreover, value could be best understood as an intersubjective phenomenon (Rooke, et al., 2010), which possibly could be mapped by tools such as Hierarchical Value Maps (Gengler, Klenosky and Mulvey, 1995). In this sense, the purpose of projects is to generate economic value, but the specification, production and delivery of value are governed by sociological values (principles, guidelines for living) (Rooke, et al., 2010).

TARGET VALUE DESIGN

TVD views AEC (Architecture, Engineering and Construction) as a complex system, which includes the project definition, design and construction stages (Zimina, Ballard and Pasquire, 2012). TVD transforms the current design practices upside down because the costs determine the design instead of the design determining the costs (Macomber, Howell and Barberio, 2012). According to Lee, Ballard and Tommelein (2012a), TVD has two key features, distinctive from more conventional practices in design development: the former is ‘Designing to targets’ in order to increase the predictability of project performance; the latter is related to a cross-disciplinary ‘validation study’ (enhanced feasibility test) in order to increase shared understanding about the basis of value/design/budget/risk.

Ballard (2011) argues that TVD is both a method that assures customers get what they need (delivers value) and also a method for continuous improvement and waste reduction. Following this idea many papers emphasize the need to develop a relationship with the client, as well as the necessity to define the client values, stakeholders values and values of the team (Ballard and Reiser, 2004; Pennanen and Ballard, 2008; Lee, Tommelein and Ballard, 2010) to deliver these so-called value(s) as result of the project. In the meantime, some definitions of value are described in TVD papers: value is an assessment made relative to a set of concerns that someone wants addressed (Macomber, Howell and Barberio, 2012), value is what customers need to accomplish their purposes (Rybkowski, Shepley and Ballard, 2012). Explicit values are defined, such as an adaptable yet durable design layout and materials (Novak, 2012).

The paper by Novak (2012) is possibly the one that best documents the practices that help create and align value with project goals in a TVD context. However, in the same paper, interviews with the project participants revealed that the design thinking and explicit project value definition had not been developed as fully as the others (target-costs). Besides, the lack of a unified vision of values, especially sustainability values, created gaps in the value creation dialogue (Novak, 2012).

Thereby, in the TVD context, the definition of what is ‘value’ is still unclear. The ‘values’ appear to be being used as a plural of value (what customers need) and not in the sense of sociological values (principles, guidelines for living). The distinction between value and values definitions have implications for lean theory and could help in practical problems for knowledge management in the built environment. In the practical implementations of benefits realisation, both values and value are negotiated between project participants/stakeholders and these processes (conversations) are implied in the basic formulation of the V theory (Rooke, et al., 2010). Additionally, the hierarchical perspective detailed through marketing techniques helps to improve the understanding of perceived value and provides useful information that can also support strategic decision-making by clients and project stakeholders (Bonatto, Miron and Formoso, 2011; Brito and Formoso, 2014; Hentschke, et al., 2014).

TVD CONTRIBUTIONS AND THE PRINCIPLES OF VALUE GENERATION

From a sample of 30 papers, 16 are identified as theoretical studies (including simulations and analysis of previous studies). The main contributions so far appear to be related to:

- adapting target costing to construction context (Jacomit, Granja and Picchi, 2008);
- outlining foundational and advanced practices to implement TVD (Macomber, Howell and Barberio, 2012) and update the benchmark in TVD (Ballard, 2005; 2011);
- improving the accuracy and feasibility in estimating and modelling costs and risks (Pennanen and Ballard, 2008; Morton and Ballard, 2009; Ballard, 2012; Lee, Ballard and Tommelein, 2012b; Ballard and Pennanen, 2013);
- improving the design process to achieve target cost (Kim and Lee, 2010; Rybkowski, et al., 2011; Kim and Lee, 2014);
- analysing and improve collaborative approaches, including integrated project delivery - IPD (Jung, et al., 2012; Pishdad-Bozorgi, Moghaddam and Karasulu, 2013; Melo, Granja and Ballard, 2013; Do, et al., 2014b).

Among these contributions, the foundational and advanced practices to implement TVD (Macomber, Howell and Barberio, 2012), when compared with the five principles of the value generation cycle (Koskela, 2000), seem to be more related to principles 2 and 3, which seek to ensure the flow-down requirements and their availability in design and production phases. Principle 1 (requirements capture) is pursued through customer/client engagement. Principle 5 (evaluation) seems to be regarded as process learning cycles. Similarly, the practices introduced by TVD Benchmarks (Ballard, 2011); also present consolidation between principles 2 and 3, although principle 1 is more present. Moreover, principle 5 appears to be considered, although exclusively related to the target cost.

Considering the contributions of 14 empirical studies (including statistical analyses) related to TVD, it is possible to highlight:

- adaptations of target costing/TVD to construction and to other countries such as the United Kingdom and Brazil (Nicolini, et al., 2000; Oliva and Granja, 2013; Melo, et al., 2014);
- demonstration of positive results of TVD implementation, specially to the projects costs (Ballard and Reiser, 2004; Zimina, Ballard and Pasquire, 2012; Denerolle, 2013; Do, et al., 2014a; Do, 2014);

- improvement of project definition and design approaches for achieve target cost (Ballard, 2006; Lee, Tommelein and Ballard, 2010; Pennanen, Ballard and Haahtela, 2010; Novak, 2012);
- improvement of management strategies and contractual approaches to apply TVD (Lee, Ballard and Tommelein 2012a; Rybkowski, Shepley and Ballard, 2012).

The studies demonstrated that most TVD projects involved private clients. In this sense, Melo, Granja and Ballard (2013) identified that the public sector owners may be limited in their ability to achieve a complete TVD application due to federal or local laws that prevent early collaboration among key project stakeholders.

Furthermore, we noticed that most TVD papers in our sample indicate some level of relationship between the practices proposed and applied with the principles of value generation. However, the focus of value generation appears to be closely linked to target-cost and all necessary environment (contracts, design and collaborative approaches) to manage costs. The other requirements, benefits and objectives of the projects are not clearly documented, described or measured in the studies.

CONCLUDING COMMENTS

The TVD approach enables a project environment with favourable characteristics to generate value, comprising: emphasis on the design activities, making the client an important participant of the process, and enhancing the client-supplier relationship, requiring collaborative approaches. However, the major focus of TVD is the target-cost, which should contribute to client value, but still the point of focus is target-cost.

From these findings, some suggestions for future studies related to value generation can be drawn to the lean construction community: (a) seek a consensus on the use of the concept of value and values, (b) apply the principles of the cycle of value generation (Koskela, 2000) in research, (c) aim to better document the capture, processing and traceability of requirements throughout the project, (d) measure the value delivered for the project clients, not only in relation to costs or objective measurements, (e) evaluate the post-occupancy phase and whole life cycle of the built facility to measure the fulfilment of requirements and the evolution of perceived value to users and customers over time.

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THE IMPACT OF VARIABILITY IN WORKFLOW

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ABSTRACT

Singularity, lack of predictability, turnover, making do, these are only a few factors that compose the process-variability in the construction industry. The knowledge of stability in activities workflow is fundamental to allow a construction company to have accurate planning. This paper evidences the impact of variability into the construction planning by using Monte Carlo simulation. It was developed the Line of Balance (LOB) of a project and generated ten thousand lead times based on the probability distribution measured on gemba for these activities. According to the simulation, the variability has a high impact on projects process time. Moreover, the delays occurred in all ten thousand events of simulation and the average delay was 12 days. In addition, the average idle time observed was 10 days and it occurred because of process-time and flow variability. According to the study, the model proves the negative impact of variability in workflow and a model to calculate LOB buffers should be developed with the intend of presenting less chance of breaks in the flow and projects delay. So, researches concerning about how to dimension theses buffers should be conducted.

KEYWORDS

Lean construction, variability, Line of Balance, buffers, Takt Time Planning (TTP).

INTRODUCTION

The scenario of the construction industry in Brazil has changed in the last decade. Until 2011, the industry has lived a very strong growth. With the increase of the demand for properties, enhanced by the fact that spending power also increase and government politics, the industry has become more representative in the Gross Domestic Product (GDP). To builders it means that incomes increased and to developers meant more launchers.

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However, with the increase of inflation and investors' low confidence, the industry had a decrease in its activity in the last year of 2.6% (CBIC, 2015). With the reduction of the industry activities, there is an even greater need to rise productivity and reduce costs, regarding the stagnation in sales and reduction on properties prices. In addition, the representation of workforce also increase and it is 57% of total project direct cost (SINDUSCON-SC, 2015).

In order to obtain a better performance, several companies have reorganized their processes based on concepts and techniques of Toyota Motor Company®. Toyota is an inspiration for many companies due to their production system based on the so-called lean thinking.

The lean thinking was originated in the auto industry, and it has proved to be effective when applied in other industries such as service industries, government agencies, hospitals, and construction (Liker, 2008).

In the construction industry, process variability is inherent and also a big issue when the final costumer is waiting to receive his property on the accorded time. For this reason the Production Planning and Control won ground in the last decade, where construction companies began to use tools and philosophies to enhance productivity and reduce wastes.

In buildings with repetitive units (similar apartments or repetitive floors), creating flow is important and a challenge. To absorb variability, buffering of time between activities is a common option, but also considered a waste.

The purpose of this paper is investigating the influence of process variability in the civil construction industry planning by using Monte Carlo simulation. This study was made with the partnership with a construction company (RDO Empreendimentos) that uses lean construction principles for almost two years.

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FLOW, VARIABILITY AND BUFFERING

Workflow is divided in dimensions: operational and process, and it is defined as all types of work conducted within available working hours – except obstructions such as downtime, rework and other forms of waste subtracted (Kalsaas, 2013). Ballard (1999) stands that Plan Percent Complete (PPC) is a measure of workflow and also the shielding that should increase it.

Koskela entitle Process Variability Reduction as a Lean Construction principle and stated that reduction of variability within process flow must be considered as an intrinsic goal for this to happen, which means finding root causes of variability (Koskela 1992; 2000).

There are two types of variability in production flows: process-time variability and flow variability. The first is the time required to process a task at a workstation, the second one means the variability of the arrival of jobs to a single work station (Koskela, 2000).

So, these concepts applies in this paper in a way that process-time and flow variability causes lack of workflow and leads to wastes causing delays and makes the activities unbalanced.

To absorb the process variability, buffers are necessary (Koskela, 2000; Yang and Ioannou, 2001; Sakamoto, Horman and Thomas 2002; Kemmer, 2006; Bølviken, Rooke and Koskela, 2014). Although they are expensive, hard to size and hardly an optimal solution (Ballard and Howell 1994). Yet to preserve the independence of one activity considering the interdependence of it with others, buffer has an essential purpose. Besides that Lean stands that buffer is Work in Progress (WIP) and is a waste that hide other wastes, and has to be minimized to expose these others wastes. Buffering is necessary in any production process and is considered a necessary mean. Somehow has to be estimated. Sakamoto, Horman and Thomas (2002) studied the relationship between activities in 3 multi-story commercial projects and developed a method to size smaller buffers between activities to enhance performance in the process as a whole.

Bølviken, Rooke and Koskela (2014) affirms that buffers are another paradox: “it is a waste to guarantee a flow level, a project without buffers, is a risky project.” Of course that a company with good expertise and accomplished a good predictability, can reduce these buffers to minimum.

LINE OF BALANCE (LOB) AND WASTES IN FLOW

Bølviken, Rooke and Koskela (2014) said that wastes in flow are divided in two groups: product flow, which would be how the product, the building, would flow in the process as a whole; and workflow, meaning the flow in the operations.

Considering a medium or a long-term plan using a Line of Balance, the wastes that could be avoided in the planning phase, proposed by Bølviken, Rooke and Koskela (2014) would be in the product flow group:

1. Space not being working in;
2. Material not being processed.

Moreover, as consequence, it will reduce unnecessary movement (of people) in the workflow group. It exists a paradox when it comes to making do (Bølviken, Rooke and Koskela, 2014). Already well known, making do is a waste presented by Koskela (2004), which is basically starting a task without having all the constrains removed. Making do in fact is a waste and needs to be removed, but in reality, it is common sense that production in gemba cannot stop, the cost is very high. Therefore, what would be worse, stop the production or start that task knowing that not all constrains are removed? Sure, that in reality, in some cases, it is easy to manage labors to a not planned task, but the consequences in scheduled must be sized.

An example is lack of material, if the project manager commands to start a task knowing that there is not enough material to finish that batch, either he should never start that batch or do what is possible and hope for the best. The same thinking works with project mistakes, security, equipment, and others.

It is common sense that the perfect scenario is everything to be in the right place, in the right time but the empirical experience of project managers and construction companies CEO`s suggests that production should not stop and everything should be done not to cause other wastes, as waiting or materials not being processed.

Kemmer (2006), Seppanen and Aalto (2005) and Bernardes (2001) held that the Line of Balance is the right technique to high buildings with repetitive floors. The tool allows better visualization of the flow in the activities and variables as batch size and cycle time should be consider.

Seppänen and Aalto (2005) stands that the Line of Balance is a graphic technique which is used to manage workflow, reduce risks, and increase productivity. One deficiency of the technique is given by the fact that it has explicit workflow but not the material flow (Bernardes, 2001).

Kemmer (2006) understood that the Line of Balance could also be used to define attack plans, by modifying the variables and analyzing the consequences in medium and long term.

The line of balance can be demonstrated in the Figure 1, where in vertical axis are described the repetitive units, and in horizontal axis is described the time in weeks or days. In the graph are described the tasks that should be done at that moment in that space. The lines inclination is called takt-time, and could be different for each activity based in the project requirements and companies' availability. By changing takt-time in each activity, the planner is forced to insert inefficiencies in the process, such as: materials (inventory), work in progress, subassemblies and stock, represented here as buffers.

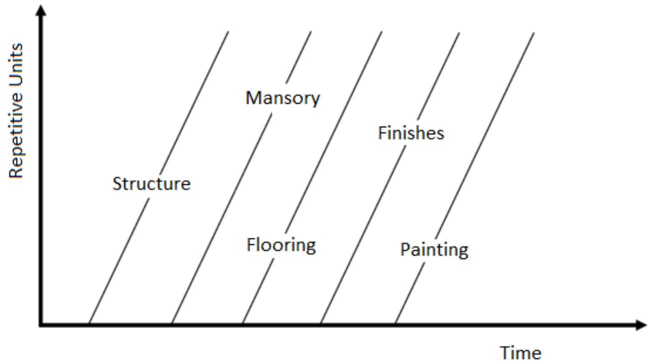

Figure 1: Line of Balance (adapted by Figure 4 of Kemmer, 2006)

RESEARCH PROBLEM

The analysis of the activities variability has been developed in a construction company called RDO Empreendimentos in the state of Santa Catarina in southern Brazil. The company has the expertise to build residential and commercial with average of 12 floors, having already built 46 buildings, 2,000 apartments, and over 330,000 square meters. Currently, the company is growing and owned six on-going projects totaling more 70.510,71m² to be built.

RDO invests in production planning and control for almost two years now, using Line of Balance (LOB) and an adaptation of The Last Planner System (LPS). The Construction Manager gives the tactical support to all projects, managing trades and equipment. The planner is required in all projects, in all planning horizons and each engineer is responsible for executing an average of two simultaneous projects and for managing all the contractors and supply requests, with assistance of an intern.

To manage its projects, the company has been improving its production planning and control system through the use of LOB. Weekly it has a meeting on gemba with all trades plus the engineer and the planner, and monthly meetings in the company's office with engineer, construction manager, design department and supply department for planning the eight week look ahead and remove constrains.

However, by analysing the company in question, it appears that – despite the implemented planning and control system and good level of learning around the use of the method – recurring problems persist. It is perceived that the cause of such problems precedes the control stage of LOB and is grounded on the planning stage, i.e. in the conception of LOB.

This problematic was identified by the company's technical team and confirmed by this study. It is related to the difficulty of executing the plan and synchronizes the activities planned at the right time. What happened at first is that the planner began planning with a big time buffer at the end of the calendar, in other words, the project's end was different of the project dead line, and the buffer was consumed little by little. Because of variability, it was causing wastes, such as: (i) stock of material – based in the delay of the beginning of each activity; (ii) waiting – generated by the complexity of manage supply to all trades; (iii) loss of productivity – caused by flow brake and making do.

Secondly, the planner started to input little buffers between activities – sized empirically, and this reduced wastes, because these little buffers absorb the variability, inherent in construction. However, the main problem still was variability, the planner observed that if more buffers were planned, few problems happen, but in the other hand, a lot of "space not being worked on" began to appear. In some cases, the takt-time at the end of the project had to be changed to guarantee that the project dead line would be respected.

Also was observed that some activities has more variability than others, caused by the complexity of constrains removal, gaps between workers' productivity, lack of quality manpower, lack of contractor commitment, climatology and costumer project changes.

It was verified the need to develop a reliable method for determining the buffers between activities in the LOB design. For this, one opted the statistical analysis of data collected from company's projects in order to find the variability of activities and thus set the buffers in the LOB.

WORK METHOD

To investigate the impact of variability in the construction planning, the present paper used the Monte Carlo simulation applied to a project planned with the LOB, and discussed about the comparison between the deadline planned and the results observed in the simulations, which contains the variability.

The methodological procedures of this paper were divided into five steps: (1) Data collection. (2) Calculation of production rates. (3) Elaboration of project plan. (4) Monte Carlo simulation. (5) Results and Analysis. Each of these steps is detailed in the following sections.

(1) DATA COLLECTION

The data used for the simulation refers to the productivity rate of six activities performed by the teams of RDO Empreendimentos Company. To generate these rates we had to discover the probability distribution of the rates based on real data collected in the field. The longitudinal section observed the period from 2013 to 2014 and used as sample five residential projects with similar characteristics and complexities, in the same region and with an average of twelve floors each. It was chosen seven preceding activities to the data analysis and calculation of productivity indexes. The chosen activities have the following description:

a) Structure - which is included the placement of forms, reinforcement structure, concrete and forms removal.
b) External block masonry – Included marking, elevation, lintels and stakes of external masonry
c) Ceiling mortar coating - which contains the application of coarse mortar and plaster.
d) Internal block Masonry - Included marking, elevation, lintels and stakes of internal masonry.
e) Sanitary system - including the installation of pipe networks to collect rainwater and sewage.
f) Cold and hot water systems - pipe networks for cold and hot water circulation.
g) Internal mortar coating - Which refers to coarse mortar and plaster application on the internal wall masonry.

Data were collected by using checklists applied on weekly basis which were stored in the ERP (Enterprise Resource Planning) system of the company. For this study, one obtained the data from the company's planning system (PPS report), where they were stored. The extracted information are related to cycle time of each repeating unit, how much was produced in this time and the number of trades required for executing each of the activities described before.

The output of this collection was a number of twenty samples per activity. In the field, it was notice that process-time variability and flow variability were detected and had influence of some pattern events. Such as: (i) learning curve; (ii) lack of commitment of last planners; (iii) making do; (iv) unexpected atmosphere conditions; (v) unexpected errors (vi) overproduction and (vii) waiting. In addition, as time passed and the company get used to the new philosophy, wastes tended to reduce.

(2) PRODUCTIVITY CALCULATION

To calculate the productivity per team indicator for each activity, were used the Factor Model approach (Souza, 2000), where the production unit rate (RUP) is adopted to measure the activities' productivity. RUP is the division of Man-Hour by the Quantity of Work: RUP=m.h/QW. In this paper, most activities' unit was measured by square feet (ft^2): RUP=m.h/ft^2.

(3) ELABORATION OF A PROJECT PLAN

After obtained the productivity rates, it was created a fictitious project, and it was given to the company's planner to plan it with his experience in the field. The planner used the LOB to establish the rhythm of activities, time buffers, and deadlines. The Table 1 presents all activities and its data (work quantitative, number of traders and duration).

The LOB was planned with a buffer with one week between activities, it was respected the concrete curing time, it was chosen a takt time of 10 working days and the planned lead-time was 160 working days. The Figure 2 illustrates the planned LOB.

(4) MONTE CARLO SIMULATION

The first stage of the Monte Carlo Simulation was to find the probability distribution of productivity rate per team of each activity and its algebraic expression.

For this, it was used the tool "Input Analyser" by the software Arena®. This software read the real productivity rates collected for each activities, and fit them into a proper probability distribution and its algebraic expression. Table 2 presents the statistical expression and distribution found for each activity.

Table 1: Characteristics of the Fictitious Project and Takt Calculation (Authors)

Activities	Qtve per floor (ft²)	Productivity (m.h/ft²)	Number of trades	Duration (hours)	Duration (days)
Structure	5.242	58,45	30	88,14	10,02
External Block Masonry	4.477	2,28	1	88,08	10,01
Ceiling mortar coating	5.166	3,92	2	87,49	9,94
Internal Block Masonry	13.454	2,28	3	88,22	10,02
Sanitary System	Bath		1	88,63	10,07
Cold and Hot water system	Bath		2	89,81	10,21
Internal Mortar Coating	22.604	1,83	4	89,36	10,15

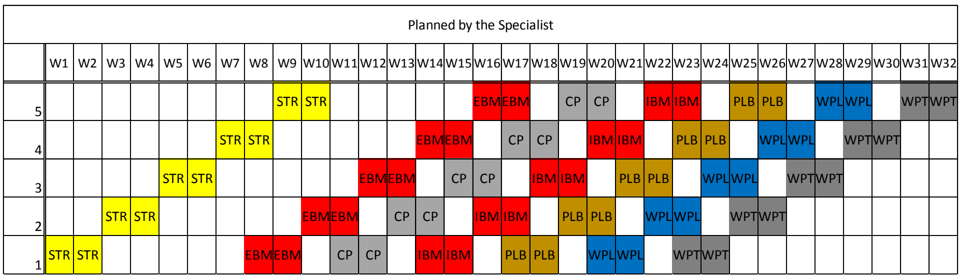

Figure 2: LOB Planner by company's Planner (Authors)

Table 2: Probability distribution and expression for each activity (Autors)

Activity	Distribution	Expression
Structure	Beta	4.37 + 1.99 * BETA(0.61, 0.703)
Internal Block Masonry	Beta	0.16 + 0.13 * BETA(0.991, 0.738)
External Block Masonry	Weibull	0.12 + WEIB(0.0732, 2.59)
Cold and hot water System	Logonormal	6 + LOGN(11.1, 11)
Ceiling mortar coating	Beta	0.19 + 0.45 * BETA(1.88, 2.97)
Internal Mortar Coating	Beta	0.12 + 0.13 * BETA(3.69, 5.7)
Sanitary System	Triangular	TRIA(3, 10, 13)

Proceeding to the second stage, was generated 10,000 random data for each productivity rate per team per activity. Considering that, the project has five floors, were generated five series of 10,000 data for each productivity per team per activity, considering their respective expression of probability distribution.

The next step was to simulate the empirical LOB with the obtained data in the previous stages. To find the difference between the real time and planned for the execution of the activities, first were found the rates of time spent by activity, i.e. dividing the productivity index by the quantitative rates provided by the empirical LOB and multiplied by the number of teams planned for the project. This has been made for all 10,000 data of each series for each activity, thereby acquiring data for direct comparison with the empirical LOB.

RESULTS AND DISCUSSION

The Monte Carlo Simulation permitted to establish 10,000 project realizations through the combination between the beginning and conclusion of the activities respecting the durations of execution randomly generated. The figure 3 illustrates one of the miles obtained combinations.

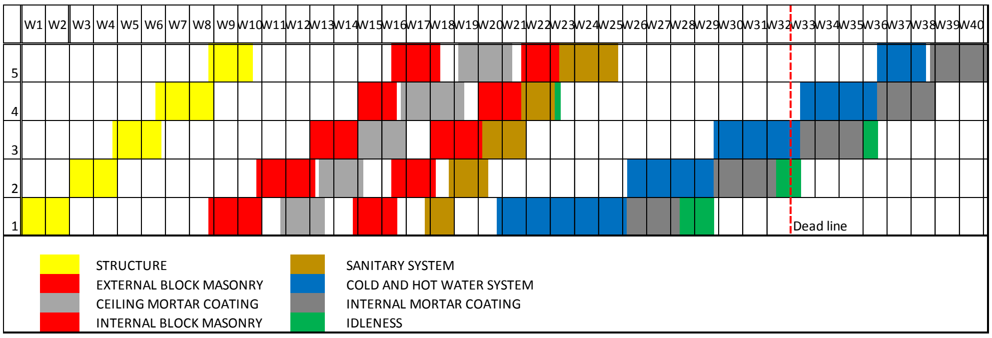

Figure 3: Example of obtained simulation (Authors)

As it can be seen at the Figure 3, the realization of the project has crossed the deadline target for the enterprise. The planned final date for the project were 32 weeks, but the variability of the activities during the execution took the project to finish at the fortieth week, which means eight days or 25% of delay.

Combining all simulations generated in Monte Carlo approach it is possible to verify the impact of the stochastic rates of productivity in the activities for the entire project performance in concern of deadline fulfillment and also idleness within the execution of the projects.

About the deadline planned target it can be seen at Figure 4 the Graph of Frequency Curve of Delay and the Graph of Cumulative Probability of Delays. As one can state, all the 10,000 simulations have exceeded the deadline planned to the project, and the maximum delay observed was 48 days, or almost 10 weeks.

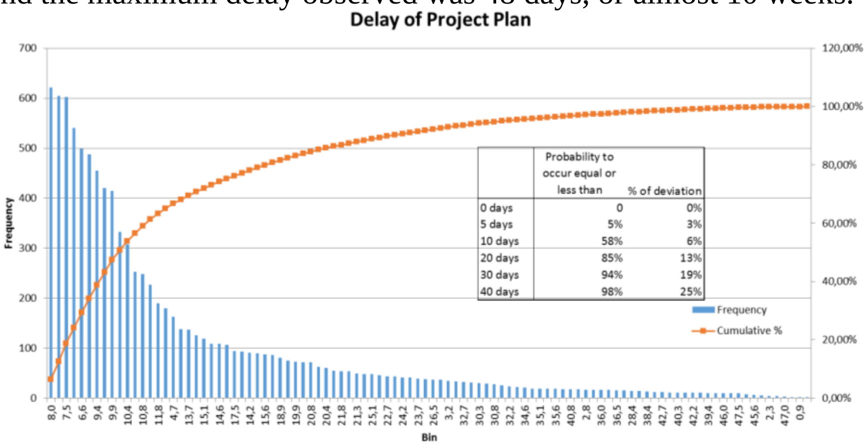

Figure 4: Graphs concerning simulated delays in project (Authors)

Concerning about idleness within the execution of the enterprise the Figure 5 brings the Graph of Frequency Curve of Idleness and also the Cumulative Probability of Idleness. As can be seen, just 6% of the total simulations did not presented idleness times during the execution of the project. The average number of projects has idleness time of about ten days, and the maximum observed idleness time was 74 days.

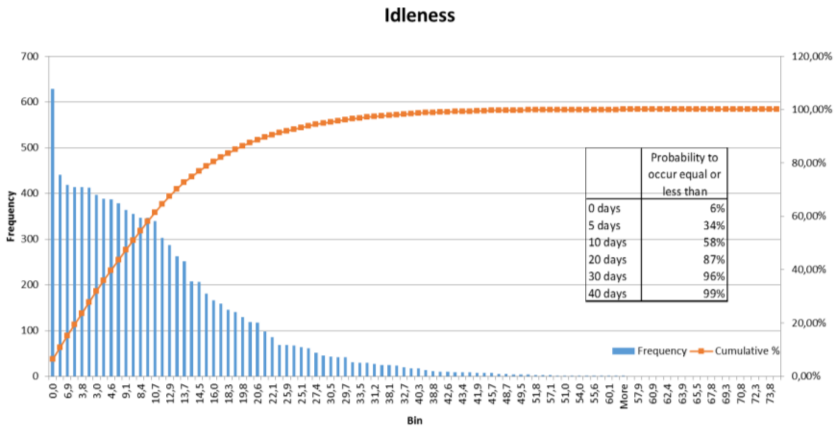

Figure 5: Graphs Concerning Simulated idleness in project (Authors)

The analyses of the Monte Carlo Simulation using the real probability distributions of activities permit to affirm that the process-time variability hardly affects the performance of the construction projects. In the presented simulation all cases have delays in the deadline, and 94% have Idleness times during the execution. These results lead to conclude that despite planners plan time buffers between activities in order to absorb variation in the process, concerning the combination of activities variability it is difficult to administrate trades in the strategic horizon. In this aspect the Look Ahead Planning and the Last Planner tools, gain importance for the integration planning, in order to try to coordinate all the teams and activities and its variability to reduce delays and idleness.

CONCLUSION

The line of balance is becoming an increasingly common planning tool on Brazilian construction companies, and shows efficiency on its purpose.

Nevertheless, when variability is not considered in the planning phase, or if it is a unknown variable and planners end up supersizing buffers, the project tends to be more wasteful.

Another point about buffering is workforce management. When the company is executing in many projects at the same time. The idea is synchronize the exit of a trade in a project and the start of another one, and buffer is input on purpose.

Also it is important to highlight that it cannot think blindly in production performance and forget the financial part of a project. Considering a scenario that the market is not responding as predicted and sales are low, on this case, buffering can be used to delay disbursements and not lose the deadline.

The study was made for a small project and few activities. In more complex projects the impact of variability should be much worse and probability of delay should increase.

Also, it was not considered any action to increase workflow and stabilize the production in this simulation. Last Planner would fit in this case by acting in the problems root causes to reduce variability.

For future studies, a model for sizing buffers between activities considering the variability flow should be investigated and tested on gemba. The aim of this model is to decrease the probability of project delay.

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USE OF VIRTUAL DESIGN AND CONSTRUCTION, AND ITS INEFFICIENCIES, FROM A LEAN THINKING PERSPECTIVE

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ABSTRACT

In recent years, the Architecture, Engineering and Construction (AEC) industry has broadly expanded the use of Virtual Design and Construction (VDC), particularly Building Information Modeling (BIM). However, this use is not always well planned and defined by the companies, which introduces inefficiencies in their VDC use.

This research explores the literature to identify examples of waste in VDC from a Lean Construction perspective, and proposes VDC practices and Lean methods to reduce this waste.

The exploratory research found examples of 8 waste types in the use of VDC: Non-value added processing, Motion (excess), Inventory (excess), Waiting Overproduction, Employee knowledge (unused), Transportation/Navigation, and Defects.

KEYWORDS

VDC, BIM, Lean, Waste

INTRODUCTION

A significant body of literature exists to describe lean production methods as well as lean construction theory and applications. Great advances have forced and enabled the construction industry, considered one of the most resistant to change, to use new methods that allow it to survive. Virtual Design and Construction VDC and Lean Construction allow the construction industry to face different challenges (Khanzode, et al., 2006; Khanzode, et al., 2007; Khanzode, et al., 2008). Multiple investigations

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converge in the potential that is achieved by implementing both initiatives together (Enache-Pommer, et al., 2010; Fischer, et al., 2008; Gerber, et al., 2010; Messner, et al., 2010; Sacks, et al., 2010; Sands and Abdelhamid, 2012; Tommelein and Gholami, 2012). This research aims to extend Lean Construction as an initiative that can "branch" throughout all processes of VDC, including information flow. As a starting point, we define the three concepts for the specific purposes of the study:

VIRTUAL DESIGN AND CONSTRUCTION

Kunz and Fischer (2011) defined VDC models as: *"The use of integrated multi-disciplinary performance models of design-construction projects to support explicit and public business objectives."* The Center for Integrated Facility Engineering (CIFE) indicates that a project is a set of information flows that can be modeled and represented in a computer using symbolic representations of Products, Organizations, and Processes (P-O-P) (Khanzode, et al., 2006). The purpose of VDC is building models of P-O-P early before a large commitment of time or money is made to a project (Khanzode, et al., 2006).

Many tools have emerged from VDC methodology, such as Building Information Modeling (BIM). Researchers have viewed and defined BIM from different perspectives. Eastman, et al. (2011) defined BIM as a modeling technology and associated set of processes to produce, communicate and analyze building models. McGraw-Hill (2009) emphasized that BIM is the process of creating and using digital models for design. That study also noted that BIM serves as a shared knowledge resource for information about a facility and a reliable basis for decision making (National BIM Standard, 2008). Kjartansdóttir (2011) viewed BIM as a process of creating and sharing data and information in a digital format.

Although the terms VDC and BIM are used interchangeably by some, BIM represents the form/scope of the product, which is a crucial but small portion of the VDC framework (Kunz and Fischer, 2011). When we reference VDC, we refer to the entire framework method (P-O-P), which has BIM as a part of the product definition. BIM relates to other methods and tools such as production models, critical path method (CPM) schedules, organizational models and 4D models. 4D refers to the four dimensions of X, Y, Z and time, i.e. 4D is 3D BIM+ schedule (time)

In this analysis, we focus on VDC as a process. A process is a structured, measured set of activities designed to produce a specified output. It implies a strong emphasis on *how* work is done within an organization, in contrast to a pure product focus emphasis on *what* (Davenport, 1993). VDC includes models, but it also includes properties of model elements, or data, as well as processes to plan, create, check and act using models.

LEAN PHILOSOPHY

Lean is a management philosophy that provides methods to identify waste and uses a number of tools and principles to remove them. Instances of waste can be found at any stage of the project, from the beginning to the information flow and the construction phase. The more waste is eliminated, the better the results (Plenert, et al., 2012). Koskela (1992) adapted the concept of Lean Production to the construction industry by formulating a new production philosophy called "Lean Construction."

Although, there are studies that point out how the impacts of VDC can be directly associated with Lean Principles (product view), the study outlined in this paper suggests that Lean Construction can help to reduce waste within the VDC in the phase of information flow (process view).

LEAN IT

Manufacturing has been a reference point and a source of innovations in construction for many decades (Koskela, 1992). In the early twenty-first century, a new approach called Lean Information Technology (IT) emerged, which aims to identify and eliminate waste within IT development processes, focusing primarily on information flow. Bell and Orzen (2010) defined Lean IT as: *"the use of Lean principles, systems and tools, to integrate, align, and synchronize the IT organization with the business to provide quality information and effective information systems, enabling and sustaining the continuous improvement and innovation processes."* Lean IT aims to improve the performance of IT processes and services. Bell and Orzen (2010) noted that the lack of Lean commitment within organizations is one of the root problems that cause failure in the implementation of IT.

LEAN OFFICE

The ultimate goal of Lean is to create a culture of continuous improvement every day, on every product or service, by everyone. Lean Office is the application of Lean Manufacturing to the administrative processes (Pestana, 2011; Ryan, 2010). A 5S is a process to ensure work areas are systematically kept clean and organized, ensuring employee safety and providing the foundation on which to build a Lean Office System (Kremer and Tapping, 2005).

METHODOLOGY

The research method for our study was an analysis that describes actual applications of VDC and Lean Construction as described in the literature. This analysis refers to methods that focus on contrasting and combining results from different studies, in the hope of identifying patterns among study results, sources of disagreement among those results, or other interesting relationships that may come to light in the context of multiple studies (Rothman, et al., 2008). Our analyses depend on the accuracy and thoroughness of the published studies we reviewed. For this paper, we attempted to gather all existing studies that discussed occurrence of waste within actual implementation of VDC practices. The analytic method adopted consists of searching, coding and providing a descriptive analysis to synthesize the findings of VDC studies that have previously analyzed. After the extensive search, we analyzed references to waste and classified these occurrences into eight types of waste reported in the VDC literature (for reasons of space, we put only seven examples of waste found in the literature).

SEARCH PROCEDURES

An extensive search of construction and related literature was initiated. Each study was subjected to inclusion rules for aggregation. A study was included if:

- The studies reported the current VDC practices (focus on the information flow).
- The studies were considered of highly quality. Two major online databases (ASCE and Science Direct) were reviewed from 2001 to 2013.

The types of waste (column 1 in Table 1) were based on the waste found in the Lean IT literature. Some of the examples are mentioned in VDC literature, while some others are not yet mentioned (Table 1). We found forty-three references to waste in the implementation of VDC in the twenty-nine papers we analyzed. Based on Plenert, et al., (2012) Table 1 defined the eight types of waste in VDC processes found.

Figure 1 shows the frequency of references to waste in cases documented in the literature. The Pareto chart shows that only five types of waste represent 80% of the references, which suggests that if teams focus on elimination of them (non-value added processing, motion (excess), inventory (excess), waiting and overproduction), they can improve VDC practices dramatically.

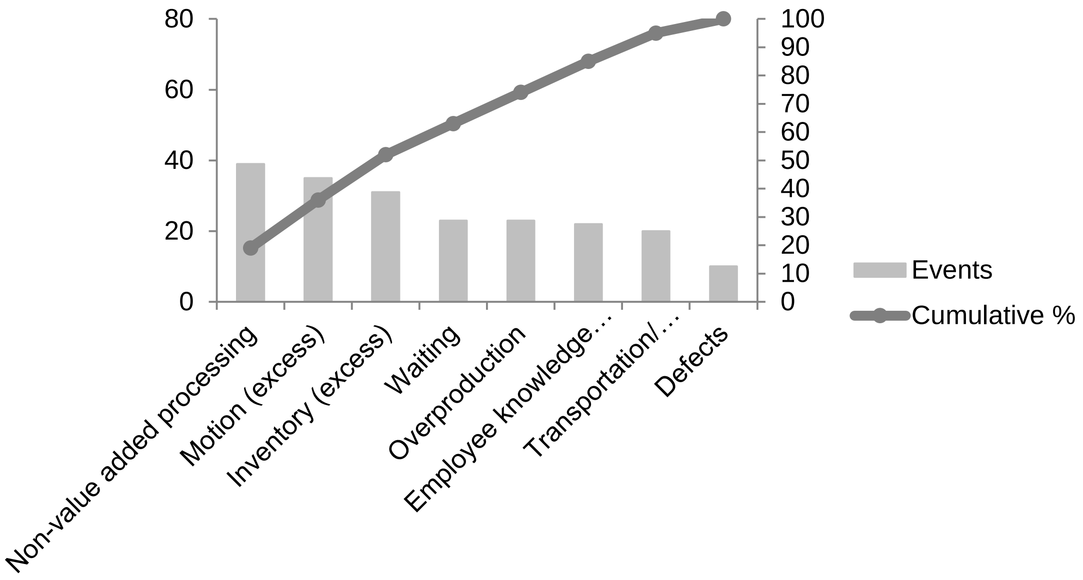

Figure 1: Number of references to waste in the literature

Table 1: Eight types of waste in VDC practices and examples found in the literature. Adapted from: Waterhouse (2008) and Plenert, et al. (2012)

Types of waste	**Definition**	**Some Examples:**	**Business outcome**
Defects	Non-conformity of a process or process step outcome.	Inadequate documentation. Defects. Rework. Poor/ incomplete documentation. Software bugs.	Poor customer service, increased costs.
Overproduction	Delivering more than what is necessary to fulfill customer requirements.	Duplicate test cases Extra features. Unused features.	Increased costs and overheads: energy, data, and maintenance.
Waiting	Idle time until arrival of a work item from a downstream process task. Delays occur between VDC activities.	Slow VDC application response times. Long synchronization cycles between application platforms. Searching for information. Delays from excessive review and approval steps	Lost revenue, poor customer service, lower productivity, and increased total cycle time.
Non-value added processing	Providing more options, functionality, and features than needed/requested by the customer.	Producing and distributing reports that are not used. Unused functionality in software. Ineffective and repetitive meetings (e.g. Big-room).	Miscommunication.
Transportation/ Navigation	Physically moving work items between subsequent tasks in a process.	Poor user interfaces. Navigate through a series of applications in order to accomplish a repetitive task.	Higher capital and operational expenses.
Inventory (excess)	Keeping available more services or material than needed or backlogs that occur in the execution of a process.	Documentation reviews. Support team queues. Multiple repositories to handle risks and control.	Increased capital expense, lost productivity.
Motion (excess)	Physical movement in the course of performing a particular task	Fire fighting repeat problems within the VDC infrastructure. People going to a meeting, not prepared (e.g. Big-room). Inefficient “movement” of data within the system.	Lost productivity.
Employee knowledge (unused)	Unconsidered knowledge and experience of people involved in the process	Failing to capture ideas. Knowledge and experience retention issues. Excessively detailed standards – no flexibility. Not investing in VDC education and training.	Talent leakage, low job satisfaction, increased support and maintenance costs.

KEYS TO A SUCCESSFUL VDC WASTE REDUCTION PROCESS

Developing an effective waste reduction process for VDC implementation is an important task before thinking about the final project results. An example is a study conducted by Freire and Alarcón (2002); based on principles of Lean production, they proposed an improvement methodology for the design process in construction projects. The authors concluded that the methodology resulted in improvements, not only for the efficiency and effectiveness of the internal engineering products, but also for the whole project. Table 2 summarizes our recommendations, based on Lean office, to reduce these kinds of waste within the VDC information flow (Kremer and Tapping, 2005; Pestana, 2011; Ryan, 2010).

Table 2: How to reduce the waste within the VDC information flow from a Lean perspective

Types of waste found in the literature	How Lean can help to reduce this waste
Non-value added processing	Use an A3 reports. Use set based design. Delay decisions until last responsible moment.
Motion (excess)	Define the scope of the models. Develop an agile process to anticipate to customer needs (customers can be internal, external, direct or indirect).
Inventory (excess)	Protocols for sharing models. BIM libraries. Meeting and quality protocols.
Waiting	Development of a communication plan.
Overproduction	Value-Stream Mapping (VSM).
Employee knowledge (unused)	Promote normalized coaching. Capture, communicate and apply experience-generated learning.
Transportation/Navigation	Develop 5S plans.
Defects	Use simple, grass-roots level suggestions to eliminate waste.

SUMMARY AND CONCLUSIONS

This exploratory research (based on literature) demonstrates there is a lot of waste in current VDC practices. Lean Thinking, as a framework, can help AEC companies reduce waste and create a more efficient VDC processes. Multiple investigations concur on the potential that is achieved by implementing both initiatives. Furthermore, VDC provides the means and methods to implement Lean Principles and incorporate management principles that help eliminate waste, reduce costs, improve productivity, and create positive results for projects. Eighty percent of the literature references represent five types of waste, suggesting that if teams focus on eliminating those five types, they can improve VDC practices dramatically. The five types of waste are:

- Non-value added processing,
- Motion (excess),
- Inventory (excess),

- Waiting and
- Overproduction

We proposed some Lean Practices that could help the AEC industry to reduce waste in its VDC implementation. For example, using set-based design can help to reduce the non-value-added processing. Value-Stream Mapping (VSM), a diagram of every step involved in the material and information flows needed to bring a product from order to delivery, can be an option to reduce overproduction. Moreover, gathering people and/or processes in order to improve workflow e.g. protocols for sharing models, BIM libraries, meeting protocols, and quality protocols can help to reduced the inventory (excess).

As we said before, this literature survey suggests that VDC practice, although clearly broadly used, seem informal in practice and clearly frequently include waste as viewed from Lean perspective. This conclusion suggests that VDC practitioners may benefit from careful attention to their VDC management processes to reduce waste, such as those that are implicit in the implementation of VDC methodology. Only when Lean principles, systems and tools are applied through every single phase of VDC practice the AEC industry can take better advantage of both methodologies.

Future research should be continued with a deeper study of information management within VDC using the lean thinking approach.

- Make a field study using Value Stream Mapping (VSM) and 5S to assess waste in construction projects for the use of VDC.
- Understanding the waste found in the literature.
- Develop models to measure the impact of strategies in the VDC implementation.

ACKNOWLEDGMENTS

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APPENDIX

Table 3: Number of references to waste within projects in the literature that reported VDC use

	EVIDENCE FROM ACTUAL PRACTICE AND/OR RESEARCH	Defects	Overproduction	Waiting	Non-value added processing	Transportation	Inventory (excess)	Motion (excess)	Employee Knowledge (unused)
1	Time spent on re-entering the data from BIM to another application is considered the main driver of additional costs. Time spent using duplicate software is ranked second in the drivers of non-interoperability. Other drivers are: time lost to document version checking, increased time processing requests for information, and money for data translators (McGraw-Hill, 2007)	•	•		•		•	•	
2	Since the lack of clarity in qualitative goals for BIM use can result in wasted effort, like over-detailing a model or not fully capturing data in formats useful to existing facility management systems (Sciences, 2012).	•	•		•		•	•	
3	The project team must employ the same reference point (0,0,0) so that the models integrate appropriately in all three dimensions. This is extremely important for 3D coordination otherwise the team will spend a lot of time trying to combine the models together for conflict detection purposes (Staub-French and Khanzode, 2007).		•	•	•	•	•	•	•
4	BIM project teams will need strong individuals to manage model input and changes. Controlling access to all the “pieces and parts” will be a daunting task. Updating and tracking model changes requires a sound document control protocol to assure all team players are using the most current version of the model (Prather, 2013).			•	•	•		•	
5	Everyone has acknowledged that digital copies are better [than paper]. My question is, how will that work going forward when you have a huge inventory of digitized information? As a result, each project has a large amount of information which makes searching for specific items more difficult. We found no consistent procedure for naming or storing information from project to project (Dossick, et al., 2012).		•	•	•	•	•	•	
6	“Electronic files could be harder to find than paper files,” and reached into his desk drawer for the hard copy. Standards go beyond naming conventions and define also the types of data to be stored” (Dossick, et al., 2012).		•	•	•	•	•	•	

Gomez, C.P., Raut, A. and Raji, A. U., 2015. Generating Value at Preconstruction: Minding the Gap in Lean Architectural Practice. In: *Proc. 23rd Ann. Conf. of the Int'l. Group for Lean Construction*. Perth. Australia, July 29-31, pp. 846-855. Available at: <www.iglc.net>.

GENERATING VALUE AT PRECONSTRUCTION: MINDING THE GAP IN LEAN ARCHITECTURAL PRACTICE

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ABSTRACT

Thermal comfort is one of the aspects of building performance which is primarily influenced by the building envelope, a primary concern in passive design strategies for buildings. A pilot study towards green value generation is being undertaken as a form of lean architectural practice using a design science approach along with the traditional production science mode. The role of the architectural technologist currently is not conceived within the value chain of the architectural practice in Malaysia. This paper focuses on the aspect of developing a sustainable hybrid wall material aimed at increasing the indoor air comfort levels in low-cost terrace housing (LCTH) in Malaysia, particularly in terms of thermal comfort. The concept of green is conceived within the enviropreneurial value chain leading to a reduction of cost - a primary concern of LCTH. The analytical device of "competency" is used to realize enhanced value generation for sustainability attainment, viewed as an expanded notion of production within building design. This situated practice of the researcher in the role of a Lean Architectural Technologist in the pilot study is conceived as being able to address the missing gap within Lean Sustainability Attainment initiatives.

KEYWORDS

Thermal comfort, learn architectural practice, building envelope, value generation.

INTRODUCTION

In recent years, scientists and the public have shown greater concern regarding indoor air quality of buildings, since most people spend more than 70-90% of their time indoors (Sharpe, 2004; Triantafyllou, et al., 2007). Buildings are less able to maintain the indoor environment comfort levels without mechanical air conditioning. It is clear that one of the major current approaches for reducing the scale of air conditioning is the application of thermal insulation in walls and roofs. Building occupants increasingly tend to use air conditioners to achieve comfortable indoor environment

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in tropical climates. The overreliance on mechanical systems for health and comfort level contributes to increasing the energy consumption in residential buildings (Uno, et al., 2012).

The design of affordable houses in Malaysia take many factors into account, however the design often fails to satisfy basic levels of spatial needs and thermal comfort (see Figure 1 and Figure 2). Due to their poor thermal design, they often overheat during the day and can be too cool during the night (Tinker, et al., 2004). Previous studies (Hanifi, 1991; Madros, 1998; Ibrahim, 2004) have also indicated that the thermal design of low-income affordable housing could be ineffective.

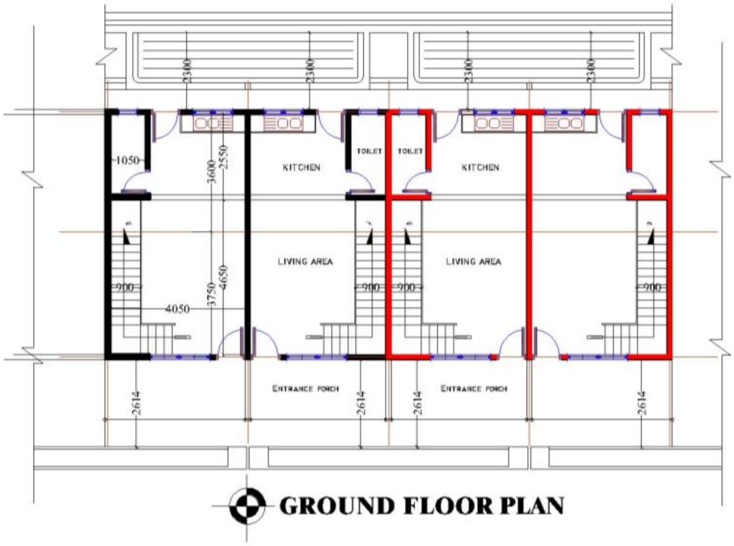

Figure 1: Ground floor plan of LCTH

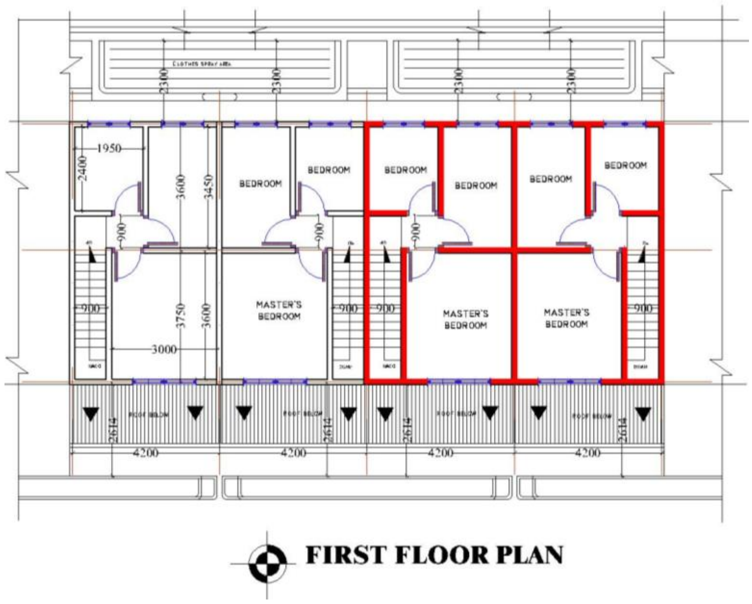

Figure 2: First floor plan of LCTH

COMMON BUILDING PERFORMANCE STRATEGIES

In reviewing extensive literature, it is evident that generally designers who try to develop and implement new materials for building performance tend to focus on resolving single objective solutions, hence creating a lacuna for addressing practical solutions that need a multi-objective approach. A major contention of this paper is that the non-existence (the gap that needs to be addressed) of professionals such as the Architectural Technologist (AT) has contributed to a lack of implementation of solutions based on multi-objective decision making in generating green value in Malaysian LCTH. This paper is part of a pilot project whereby the researchers take on the role of an AT, more so oriented towards that of a Lean AT. The primary concern here is to address the much neglected sustainability characteristics, primarily that of environmental and economic sustainability, rather than solely focus on the physico-mechanical characteristics in the development and selection of wall materials.

Several researchers have investigated various building performance strategies to improve indoor air comfort levels through passive design. Feng (2004) points out that to design energy-efficient buildings, design variables and construction parameters need be optimized. Consequently, the initial step in addressing the low indoor comfort levels is to identify the design variables that are directly related to heat transfer processes. In reviewing the work of Stevanonic (2013) on various research on design parameters for heating/cooling load and thermal comfort, it is evident that there is lack of research aimed at improving thermal transmittance values (U value) of wall material. Ekici and Aksoy (2011) summarized the parameters that affect building energy requirements as in Table 1 below.

Table 1: Building energy requirement parameters (Ekici and Aksoy, 2011)

Physical Environmental parameters	Design Parameters
Daily Outside temperature (^{o}c)	Shape factor
Solar Radiation (W/m^2)	Transparent surface
Wind Direction and Speed	Orientation
	Thermal–physical properties of building materials
	Distance between buildings

RETHINKING BUILDING PERFORMANCE STRATEGIES FOR ACHIEVING THERMAL COMFORT LEVELS

Malaysia is located within the Equatorial Zone and therefore its climatic temperature is generally stable throughout the year, ranging between 27°C and 32°C during the day and 21°C and 27°C during the night. There are large variations in rainfall but relative humidity is high throughout the year, at about 75% (Tinker, et al., 2004). It is noted by Wahab and Ismail (2012) that hot and humid air is likely to be trapped indoor for the whole day which causes increase in indoor temperature. However, in comparison, the outdoor environment is relatively more comfortable for at least 14 hours per day. It is evident that even the minimum 10% opening size with respect to the floor area requirement under the Uniform Building by Law 1984 is unable to address the problem of high indoor air temperature. Hence, rather than resort to active cooling mechanisms, the focus here is to address the avenue for replacing conventional building envelope that have high U-values.

Designers predominantly pay less attention to seek out “better” constituent materials. Thus, the use of traditional construction materials such as clay bricks continue to dominate as primary wall material in LCTH projects and this affects the sustainability aspect of such projects. This is viewed here as *‘sustainability negligence’* in the selection of materials. In the Malaysian construction industry, materials selection according to specification is not currently assigned to being within any specific management portfolio. It is argued in this paper that there needs to be a clear sense of responsibility accorded to the Architectural, Engineering and Construction (AEC) team in the specification, selection, handling, storing and application of materials under the broad category of technology management. There is an urgent need for bridging the gap in construction practice between design and green technology management which can be fulfilled by the architectural technologist. This gap in construction practice is viewed as an issue dominated by the lack of competence in green innovation within the AEC team.

ROLE OF LEAN ARCHITECTURAL TECHNOLOGIST

Positioned between conceptual design and production, the AT forms a creative link in the value chain (Emmitt, 2009). Concerned with the technical side of design, they ensure that an attractive functional building performs successfully. They make sure the right materials are used and that building regulations are met. They also monitor quality assurance, costs and deadlines and will help to lead projects from conception through to completion. One of the important tasks of AT is to recognize how the design aspects of a construction project influence and relate to performance and functional issues so that practical questions can be addressed at the outset.

AT is an emerging profession, the role of the AT has changed and developed as building design and construction has become more specialized (Emmit, 2013). The Royal Institute of Architects Ireland regards “the professional AT as a technical designer, skilled in the application and integration of construction technologies in the building design practice”. The role of the AT is scoped under the field of architectural practice. But, then how can an AT specifically function within the confines of the concept of affordable homes? It can best be achieved by working in a design science mode that is underpinned by an enviropreneurial value chain (EVC) enhancement philosophy (described briefly under the methodology section of this paper). Design Science is an inventive or creative, problem solving activity, one in which new technologies are the primary products (Rocha, et al., 2012).

Following Rooke, et al. (2007), in their attempt to extend lean production theory to examine the production of organization, this paper is an attempt to extend lean production theory to examine the production of design by focusing on ‘competencies’ or ‘abilities’ as the prime analytic device for understanding operational flows for generating improvement innovations, specifically green innovation in LCTH. Here, the competency of the AT is viewed as the critical link in generating added green value within the analytical framework of operation flows which centers on the worker, as originally proposed by Shingo (1988). Additionally, in the case of LCTH it is also important to focus on keeping costs down.

Researchers have identified the use of Lean Construction Principles to increase environmental benefits (Huovila and Koskela, 1998; Horman, et al., 2004; Luo, Riley and Horman, 2005; Riley, et al., 2005; Lapinski, Horman and Riley, 2006), focusing on waste elimination, and pollution prevention and value maximization for customer. Attempts to be green without being lean is seen as a contradiction. Lean practices can be more readily adopted in a construction project at design phase to reduce costs and enhance sustainability by leveraging on the EVC concept, to be undertaken by the LAT. EVC attributes can lead to reduction in cost in the process.

This paper focuses on the concept of maximizing value from a passive design strategy in terms of the building envelope, particularly that of wall material; a much neglected area of focus amongst lean researchers - the missing link within current lean design practice and research that does not favour a design science approach. Additionally, the aim is to eventually steer current initiatives involving non-LCTH projects away from traditional practice towards lean green building design in Malaysia. Currently conventional design is reviewed and amended to cater for sustainability features at the post-design phase. This is practiced by Green Building Facilitator (GBF) teams in Malaysia to propose enhanced green attributes to the existing design to achieve Green Building Index certification. This approach is solely transformational, without emphasis on the flow theory of production and value generation theory of production. Hence, the relevant competencies of a number of individuals from architectural practice, quantity surveying, mechanical & electrical engineering etc. of the GBF team is proposed in this paper as being centered under one portfolio in lean green building design practice, within that of the LAT.

GREEN R&D WITHIN PRODUCTION ENVIROPRENEURIAL VALUE CHAIN

A green value chain refers to the lifecycle of a product beginning with the initial sourcing, through research and development (R&D) and production, all the way to the final recycling of waste and product abandonment. Porter (1985) pointed out that the most important target of a firm is *value creation*, and any series of complex activities aimed at creating value forms a value chain. This is because clients must believe that the real value of a particular product or service exceeds the amount on the price tag and the price is always set beyond the cost of production, it is a firm's priority to improve the perceived value of a product or service and reduce the cost of production.

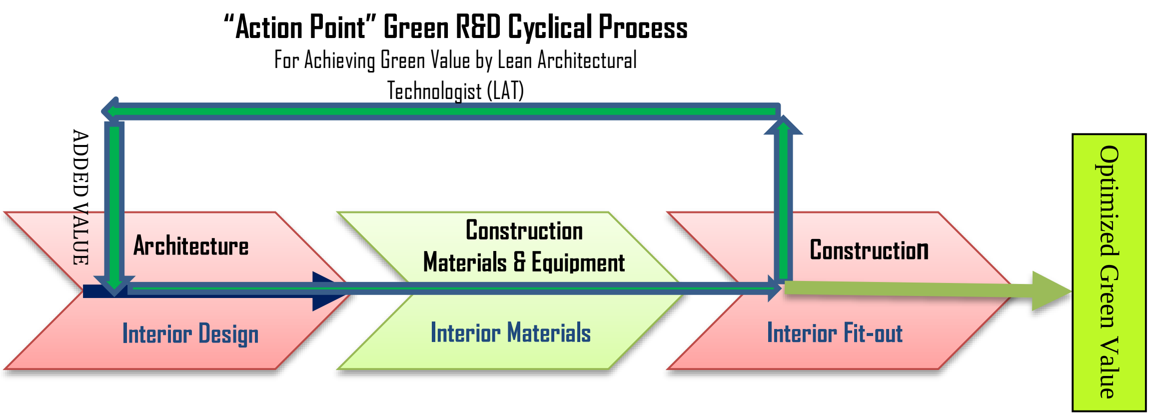

Figure 3: Role of AT in green building design value chain for LCTH (Adapted from Doery, 2009)

The LAT is seen as key player in the green building value chain based on operational flow perspective, providing the much needed technical support for green value creation in the design and construction process (see Figure 3). The Lean AT will identify "action points" for modifying the traditional linear value chains to achieve *optimal green value* for the client working to provide green solutions using a design science research (DSR) methodology underpinned by the EVC approach, whilst also serving to supervise the implementation at the construction phase. Following Kung, Huang and Cheng (2012), the green value chain consists of six major aspects: green sourcing, green R&D, green production and manufacturing, green marketing, green promotion and education, and recycling.

Hartman and Stafford (1988) point out that the traditional linear value chain is based on the assumption of closed-loop *resources*, whereas the green value chain emphasizes a closed-loop *process* involving the production and use of high-value products, based on the concept of EVC. Here, additionally the value chain is viewed within business processes. The implementation of EVC attributes can lead to reduction in cost in the process, a vital moot point in the initiative of the Lean AT to minimize cost and waste whilst maximizing green value for LCTH in Malaysia.

RESEARCH METHOD

The methodology used is a design science methodology alongside the traditional production science approach. The analytical device is that of "competency". As architects are generally focused on form over function, it is argued here that their architectural practice could benefit by being complemented with the role of the AT. The attempt here is to maximize value through the value added competency of the AT in undertaking Green R&D. The role of the researchers in this pilot project is fundamentally seen as taking on the role of the Lean AT in using a design science approach to develop a hybrid wall system for improving indoor thermal comfort levels centred on design flows and green value creation.

The AT has to play important role in consultation with the designers in implementing passive and active design strategies during the design stage. As per Malaysian context, it is evident that AT whose role includes the contribution to the value chain to generate green value (in terms of thermal comfort) is non-existent. There is an urgent need for professionals who can address deficits in functional building performance attainment, especially during the pre-construction stage of a project to be emplaced in the construction value chain process. This role is proposed as best served within the broader context of Lean Architectural Practice. It is proposed here that in order to achieve green without being lean is a contradiction.

CONCEPTUAL FRAMEWORK FOR IMPROVING THERMAL COMFORT

Design science research (DSR) approach is adopted by the LAT within the perimeters of enviropreneurial value chain (EVC) processes aligned towards lean practices of minimizing waste and maximizing value. DSR aims to solve practical problems while also providing a theoretical contribution. The EVC process analysis attributes and lean practices provide the contextual rules for green R&D whilst keeping cost low. A system development research process (a subset of design science) is being adopted which was proposed by Nunamaker, Chen and Purdin (1991) for systematic problem solving. The system development research process is composed of five stages or activities (with backtracking) including: (1) construct a conceptual framework, (2) develop a system architecture, (3) analyse and design the system, (4) build the (prototype) system, and (5) observe and evaluate the system. Fig 4 shows the conceptual framework for solving thermal comfort problems in low cost terrace housing (LCTH).

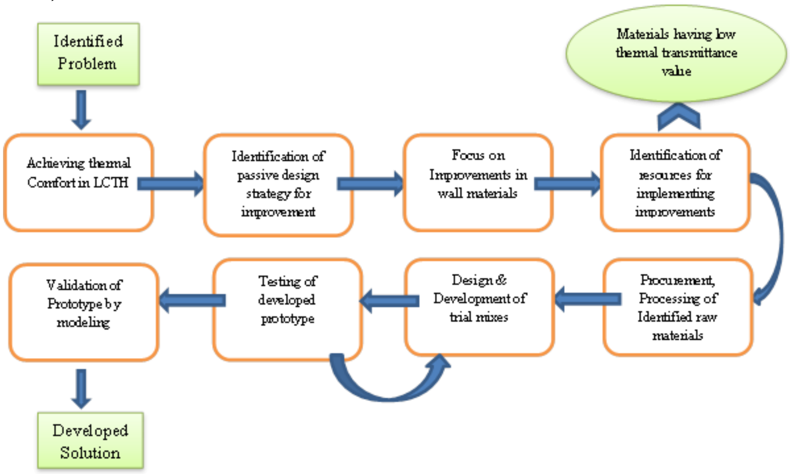

Figure 4: Conceptual model for developing a solution for thermal comfort in low cost terrace housing (LCTH)

U value of opaque envelope system in Malaysian houses vary from 1.0 to 4.0 W/m^2 K and overall thermal transmittance value (OTTV) limit for wall in Malaysia is 45 W/m^2 K. Typical U-value of brick and concrete walls used in Malaysia is 2.15 W/m^{2}K (Saidur et al., 2009). European standard EN832:2000 states that, depending on the location and climate, walls should be made of material with a heat transfer coefficient of 0.4–0.7 W/m^2 K, the lower the better. This proposed hybrid wall is currently in the initial stage of development. The R&D conceptual framework for this research is shown in Fig. 4, aimed at developing an appropriate green hybrid building wall material to replace the high U value traditional wall material that mainly consists of bricks and mortar (see Fig. 5).

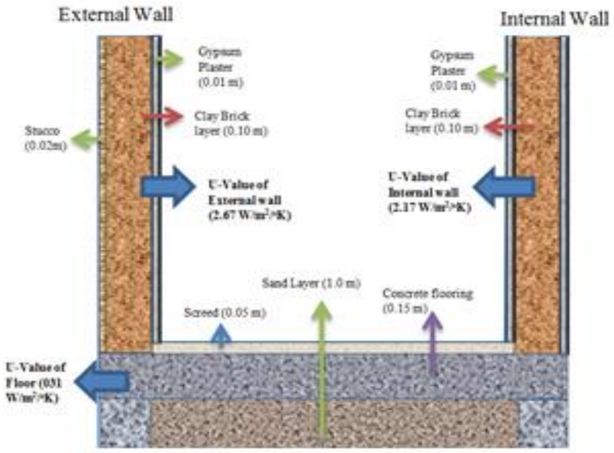

Figure 5: Cross-section of current wall system in LCTH and their U values

Certain types of waste materials are being explored for their respective thermal and mechanical properties, namely rubber crumbs, powdered glass, fly ash, oil palm fly ash and textile waste - which in hybrid combination can have low thermal transmittance value as compared to conventional materials. This is initially being simulated based on mathematical modelling using MATLAB. Selecting waste for utilization is complex as some of the waste material can have adverse effects due to their undesirable characteristics. Foreseeing this issue a combination of materials are to be chosen so that the final product should not compromise on green value. Green materials do the most with the least, and fit most harmoniously within the ecosystem process; also helping to eliminate the use of other materials and energy whilst contributing to the attainment of a service-based economy. The hybrid material prototype will be modelled based on a multi-criteria decision making model.

COMPETENCY CONCEPTUAL FRAMEWORK FOR GREEN VALUE OPTIMIZATION

In using the analytical device of competency from a design science and production science perspective, a conceptual framework for green value optimization is forwarded (see Figure 6). Wherein, the 'technical skills', 'technical knowledge' and 'enviropreneurial value analysis' that come under the design science and production science category are attributes of competency. Here, the LAT will work alongside the architect after the preliminary design phase to optimize green value within the broader enviropreneurial value chain underpinned by lean design principles.

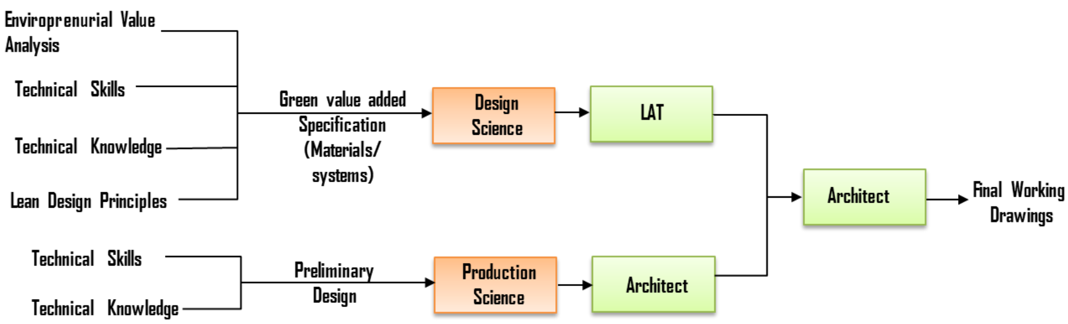

Figure 6: Competency conceptual framework for green value optimization

CONCLUSION

This paper acknowledges that there is increasing relevance of Lean to the broader construction process, and the need to apply extended lean production theories to the design process, specifically in contributing to the green value chain. Hence, it is contended here, that the role of the LAT can serve to establish more clearly this relevance by applying the TFV view to design. Here, the research strategy is to solve the practical problems from a design science approach underpinned by lean principles and enviropreneurial value chain attributes. As the focus in this case is on low cost terrace housing (LCTH), the development of the hybrid wall material will not only have the requisite thermal properties, but strong sustainability performance criteria and a cheaper option, done by incorporating locally available cheaper materials. Hence, a mapping for sourcing of such materials within Malaysia will be produced based on secondary data to facilitate the implementation of this green hybrid wall concept. It is proposed that universities in Malaysia be the Lean Architectural

Technology Centres, the hub of this Green R&D, with university researchers taking on the role of the LAT.

The inputs given by such a dedicated professional who can create the “pull” factor based on flow theory of production for value-added building design and product features can fill the vacuum between conventional design strategies and dynamic sustainable development agendas. Herein, referred to as a competency gap, within the green building value chain - a glaring disconnect within Lean Architectural Practice. Certain crucial inputs such as use of green materials, insulation, natural ventilation, etc. to create better indoor environment eventually adds value to end users in terms of functionality.

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KEYWORD INDEX

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