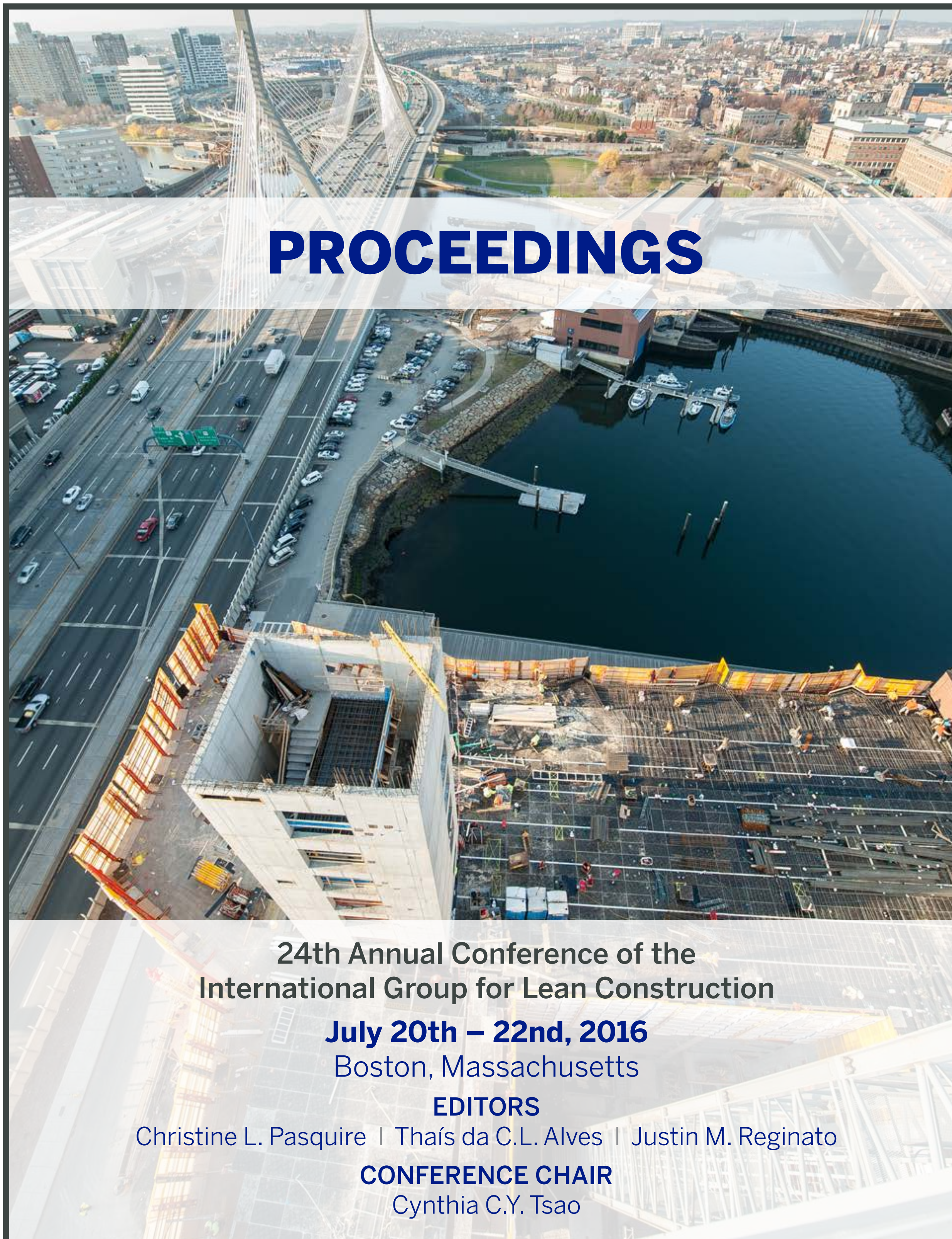
IGLC 2016 BOSTON
INTERNATIONAL GROUP FOR LEAN CONSTRUCTION

ON THE BRINK OF THE LEAN REVOLUTION



PROCEEDINGS

24th Annual Conference of the
International Group for Lean Construction

July 20th – 22nd, 2016
Boston, Massachusetts

EDITORS
Christine L. Pasquire | Thaís da C.L. Alves | Justin M. Reginato

CONFERENCE CHAIR
Cynthia C.Y. Tsao

IGLC2016

"On the Brink of the Lean Revolution"

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Conference Chair: Cynthia C. Y.Tsao

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Foreword

We would like to welcome you to Boston for IGLC24! Since it was first settled in 1630, Boston has served as a hub of innovation and industrial advancement in North America. It is an appropriate host city for a conference that showcases the leading edge research of the Architecture-Engineering-Construction (AEC) industry. The conference Gemba office and jobsite visits were designed to illustrate both standard and cutting edge lean techniques that are permeating the design and construction industry, many of which were born from the research presented at previous IGLC conferences. Boston is considered the epicenter of the United States' revolution to become an independent nation and it is no coincidence that the theme for IGLC24 is "On the Brink of the Lean Revolution". The activities and papers presented at IGLC24 certainly demonstrate that we are indeed on the cusp of a lean revolution!

The conference statistics demonstrate three things, firstly the continuing growth of the IGLC conference, secondly an increasingly rigorous reviewing process and thirdly the global spread with papers published from 20 countries including: Australia, Brazil, Chile, Columbia, Finland, Germany, India, Israel, Italy, Lebanon, Morocco, Netherlands, New Zealand, Norway, Peru, South Africa, Sweden, Taiwan, United Kingdom and United States.

Abstracts reviewed	Full papers reviewed	Papers published	Keynote papers	Track papers	Poster papers
242	184	123	13	70	40

This created a conundrum for the editorial committee: how do we organize the conference so that we can maximize the exposure of 123 papers? After careful consideration, we organized the papers into two categories: those that will be allotted time for a formal presentation and those that will be presented during formal poster sessions. This year we have taken a positive step to improve the perception of this mode of presentation. Posters represent research that is confronting major issues in the AEC industry and need to be brought to the attention of the IGLC community. Often these papers represent early stage research, but on many occasions, the Technical Chairs found themselves saying, "We need to make room during the conference to give this work a dynamic stage so that it can be disseminated." Poster sessions allow for greater audience engagement than traditional presentations, and many research communities in science, medicine, humanities, and social sciences use posters as their main form of presentation. Learning from these other research communities, IGLC24 arranged for attendees to vote online for the top poster presentations with the "Best Peer Reviewed Poster Presentation" announced during Thursday night's Research Conference dinner. We truly feel this will be a lean way to expose to all the excellent work submitted to the conference and we hope you enjoy the format.

As is common for IGLC conferences, Product Development & Design Management, Production Planning & Control, and Theory are the most popular tracks. The largest group of papers, 22, were for **Product Development & Design Management**, demonstrating how much lean has infiltrated the design community. **Production Planning & Control**, the traditional cornerstone of lean design and construction research, has submissions that tackle the always important topics of waste reduction, work flows, and production tracking. **Theory** continues to be a stalwart of IGLC, and the18 contributions continue to push how we think about lean design and construction.

Perhaps the most telling sign of the impending revolution is the growth of papers in the **Enabling Lean with IT** and **People, Culture and Change** tracks. The AEC industry is routinely criticized for its resistance to change and technology adoption, but work presented at IGLC24 demonstrates that change is happening rapidly, both in people's mindsets and the tools they use to enable lean, in both the developed and developing worlds.

Work presented in the **Supply Chain Management and Prefabrication** track exhibits not only how common lean processes like JIT and prefabrication are in construction projects, but also how sophisticated the techniques are becoming. While we typically focus on applying lean to design and construction activities, suppliers are leading the way in terms of adopting lean and enabling it on project sites. Similarly, the **Production System Design** track looks at projects at a granular level with lean techniques such as takt time planning, but also on a global scale with optimization of on-site production systems. It also looks at taking lean design and construction principles and applying them to, of all industries, the film making industry.

To people new to lean design and construction, there seems to be a misconception that lean is applied only to field operations and is led by last planners such as foremen and superintendents. Yet the **Contract and Cost Management** track provides papers covering a host of topics, notably target and activity-based costing, demonstrating the prevalence of lean in the preconstruction phase. It similarly provides papers discussing alliances and timely involvement of contractors in projects which are increasingly important in the widespread adoption of lean.

A common staple of construction is managing quality and safety, and IGLC24 acknowledges this. Contractors oftentimes associate safety and quality by adherence to rules and specifications, but the work presented at IGLC24 demonstrates a new, forward thinking and proactive approach to ensuring worker safety and quality assurance. The **Safety and Quality** track showcases work in a wide area of study, ranging from ergonomics to the use of unmanned aerial vehicles to perform safety audits, and very interestingly, the implications associated with the use of counterfeit materials.

Lastly, although only three papers were selected for the **Teaching Lean Construction** track, there were additional papers that discuss teaching lean. This area of research is highly promising and is evidence that the lean revolution is upon us. Once lean becomes embedded in the curriculum of construction education, the lean revolution will have firmly taken hold. Many of these papers discuss simulations that will facilitate the teaching of lean design and construction and one particular paper investigates the lean skills and qualifications employers are looking for in new employees. It will not be long before construction personnel will be selected for projects specifically based on their ability to foster a lean environment.

The success of IGLC conferences is a group effort, and IGLC24 was no exception. We know it takes extraordinary effort to conduct meaningful research and write and refine papers. With the timeframes we worked with, we appreciate the efforts of the authors to meet tight deadlines.

Your efforts were matched by those of our reviewers. A lot of behind-the-scenes work was performed by our team of reviewers and this conference would not be possible without their extraordinary effort. Every paper received at least two reviews, and the bulk of the feedback was candid and constructive. It represented the best efforts of the lean community to foster the growth of significant research that will improve the AEC industry.

In addition to being a cradle of innovation, Boston is an international city. Its institutions of commerce and higher education attract people from around the world who collaborate on projects that reshape our lives. That same spirit is emblematic of IGLC. The people working diligently to improve the AEC industry will converge for one week in Boston to discuss, debate, collaborate, and challenge each other to advance lean design and construction. Every revolution begins with challenging the status quo and IGLC routinely challenges the hidebound AEC industry. Thus, IGLC24 will demonstrate clearly that we are “On the Brink of the Lean Revolution”.

We hope you find our conference thought provoking, enjoyable and above all friendly. If it is your first visit - welcome to the IGLC family!

July 2016
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Technical Chairs of IGLC24 and Editors of the Proceedings

Cynthia C. Y. Tsao
Conference Chair

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SECTION 1: THEORY

Bolviken, T., and Koskela, L. (2016). Why hasN'T Waste Reduction Conquered Construction?
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WHY HASN'T WASTE REDUCTION CONQUERED CONSTRUCTION?

Trond Bølviken[1] and Lauri Koskela[2]

ABSTRACT

Waste and waste reduction are some of the main concepts that differentiate lean thinking from other approaches to production planning and control. Since its introduction in the West in the 1980s, the concept of waste reduction has had a major impact in manufacturing. But not so in construction. This paper raises the question of why this is the case. Possible answers are sought not only in the mainstream theories of production and construction management but also in the specific characteristics that distinguish construction from manufacturing. Eight possible answers to the question are identified and discussed. The paper concludes by arguing that many of the identified reasons are in fact being addressed by newly developed Lean Construction concepts.

KEYWORDS

Waste, Construction, Manufacturing.

INTRODUCTION

In lean production theory, the concept of waste derives from the Toyota Production System (Ohno 1988, Shingo 1988 and 2005). It has proven worldwide to be a powerful approach to improving productivity in manufacturing. It is used at the macro level of business models and value chains, at the mid-level of production system design, and at the micro level of task execution. The original list of seven wastes presented by Ohno (1988) is still in broad use, but a substantial number of changes have also been proposed, particularly as a result of adapting the concept of waste to types of production other than manufacturing (Koskela et al. 2013, Bølviken et al. 2014).

Construction is one of the major industries worldwide, and is commonly recognized as having high levels of waste. It can therefore be viewed as something of a paradox that waste reduction has not become a dominant strategy with regard to improving productivity in this industry. The topic of the present paper is to identify possible explanations as to why this is the case.

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We have not identified any literature explicitly addressing the question put forward in the present paper. There are however some contributions on the related, but more general question of barriers to implementing "Lean" or "Lean Construction" in the construction industry (Mossman 2009, Bashir et al. 2010, Sarhan & Fox 2013, Wandahl 2014). Based on a review of literature on barriers to the take up of lean practice, Bashir et al. (2010) find that these barriers can be grouped in the following six categories: management, financial, educational, governmental, technical and human attitude issues. (Sarhan & Fox 2013) is the only of the identified contributions with specific references to waste reduction. These references are however to sources of waste, rather than barriers to waste reduction.

METHOD AND STRUCTURE

The approach of this paper is theoretical. Eight possible answers to the question raised in the title of the paper are identified and discussed. The paper concludes by looking at how existing Lean Construction concepts relate to those answers.

OUR THEORIES AND THE WORLD

In contrast to Plato's idealistic view that the world of ideas is more real than the material world, which is only an imperfect image of the former, lean thinking reflects Aristotle's philosophy of understanding the relationship between the real world on the one hand and our ideas and theories of this world on the other, as a two-way connection. The world influences us, and we influence the world. In this perspective, our ideas, values, terms and theories can be seen as a lens between the world and us. On the one hand, this lens influences how we experience the world, on the other it also influences how we choose which actions to take and how we view the consequences of these actions.

When trying to understand why waste reduction has conquered manufacturing but has not got off the ground in construction, our approach will therefore be to seek the answers to this question from two approaches:

1. *Answers related to our theories on the world*. The theories relevant to our topic are the mainstream theories of production and project management. The mainstream theory of project (or production) is provided by the transformation view on operations. In this view, a project is conceptualized as a transformation of inputs to outputs (Koskela 2000). In turn, the understanding of management is based on three theories: management-as-planning; the classic communication theory; and the thermostat model (Koskela & Howell 2002).
2. *Answers related to what the world is like*. The world in question is construction. The question of what the world is like can therefore be reformulated to what features distinguish construction from manufacturing, or: What kind of production is construction? These questions have been discussed by several authors (among others Ballard and Howell 1998, Koskela 1992 and 2000, Vrijoef and Koskela 2005, Bølviken 2012, Bertelsen 2003 and 2015), focusing on topics like temporary organization, one-of-a-kind products, site production (the product is rooted to the ground), heavy regulatory framework, and high level of complexity.

IDENTIFIED EXPLANATIONS TO THE RAISED QUESTION

In the following we will present eight possible explanations to the question raised in the title of this paper. The first four address how we see and understand the world (i.e. consequences of the mainstream paradigm of production and construction management); the last four address how the world is (i.e. what kind of production and industry construction is).

CONSTRUCTION MANAGEMENT IS SEEN AS THE MANAGEMENT OF CONTRACTS RATHER THAN THE MANAGEMENT OF PRODUCTION

Waste is a concept embedded in the concepts of production. However, construction is not always viewed as production. Rather, since the mid-20th century, the organization and management of construction has increasingly been influenced by the view of construction as procurement, or buying, of the different inputs.

Pre-war construction was often an in-house activity. Bigger industrial companies had their own construction departments. Contracting companies hired labour directly. Along with changes both in construction technology and management thinking, the use of subcontractors gradually became prevalent, eventually arriving at the current situation where subcontractors perform the vast majority of the work.

However, this has also influenced construction management. Whereas earlier contracting companies had been keen to carefully manage production to avoid any unnecessary costs (indeed, waste), their attention was now turned to contract management, to ensuring that the agreed output was being provided by the subcontractors. A witness of this evolution writes (Allen 1996):

> Suddenly there was a contract between the manager and the production process and yet we still acted as if we directly controlled the work face. The contractual problems that inevitably arose required a fix, and we started down the road to managing contractors, not production.

Although the main contractor continued to provide a master schedule, its efforts towards careful production management were reduced. The unnecessary costs of the subcontractors were not visible to the main contractor, and thus the waste in the production process failed to attract its attention. Of course, each subcontractor endeavours to avoid unnecessary costs, but as the work in many ways is usually intertwined with the activities of other sub-contractors, these pursuits are constrained at the outset.

THE CULTURE IN (PARTS OF) THE CONSTRUCTION INDUSTRY

It has been widely observed that the mindset and the culture of construction are oriented to firefighting, to solving problems as they occur rather than prevent them arising in the first place. This may be due to the endemic weakness of management in construction but perhaps also to the weakness of managerial ideas. This situation is also common in project-based industries, as shown by the results of Wearne (2014):

> …the results indicate that more than 75% of the problems are due to institutional practice within organizations rather than inherent in their projects. Many of these problems of project management could therefore be avoided, or at least reduced by early attention to their causes. As a result, much of what is called "fire- fighting" in project management—

urgent actions on problems that should not have been allowed to occur—could be prevented.

The firefighting mentality implies little interest in proactive avoidance of problems, leading to waste. Rather, the rapid and efficient solution of the problems is appreciated.

IN CONSTRUCTION THE FLOW PERSPECTIVE IS UNDERSTOOD FAR LESS THAN THE TRANSFORMATION PERSPECTIVE

In the 1960s, the critical path method (CPM) rapidly diffused as a modern method of construction management (Moder & Phillips 1964) and, indeed, the whole discipline of project management evolved based on CPM. The notion of task is central in CPM: it is tasks that are comprehensively identified through a Work Breakdown Structure and then planned, executed and controlled. Conceptually, task is based on the transformation model of production. This is a black box model, abstracting time away, which depicts only the input and the output of the transformation, rather than the transformation itself (of course, in CPM, time is included but it is external to the conceptualization of tasks). Waste occurring inside the productive transformation is not visible in this concept.

Through the diffusion of CPM as well as wider project management ideas into the teaching and training of construction management, and progressively also into practice, this task-centred view on construction has effectively directed attention away from waste.

THE CLASSIC LIST OF SEVEN WASTES IS NOT FULLY RELEVANT FOR CONSTRUCTION

The success of the famous classic list of seven wastes in manufacturing is founded on its practical and intuitive qualities, and neither Ohno nor Shingo present theoretical arguments for the list. In manufacturing, the list has been instrumental in clarifying the concept of waste and also in identifying waste. Among the seven wastes, Ohno pinpoints overproduction (essentially, producing something too early) as the most important type of waste. The elimination of overproduction ideally requires that the production cycle is compressed to be the same or shorter than the ordering cycle of the customer so that the pull principle can be used. This, in turn, requires the elimination of all slack, in the form of inventories, from the production cycle time (Koskela et al. 2013).

In car manufacturing, overproduction manifests as large intermediate inventories and as cars produced without an order from a customer. Barring speculative building of housing or offices, the situation is different in construction: it is engineer-to-order production at the outset. Indeed, in general a construction project is completed late rather than too early.

Thus, as Koskela (2004) and Koskela et al. (2013) argue in more detail, the concept of overproduction as the most important waste does not hold in construction. Rather, as Koskela et al. (2013) explain, the characteristics of construction lead to an erosion of the integrity of tasks, both at their start and end: making do and task diminishment. In order to have an effective grip on waste in construction, these two phenomena need to be understood and controlled.

As a contextualized analysis of waste in construction has only recently emerged, it can be argued that the mismatch between the manufacturing waste theory, widely popularized, and the factual situation in construction has hindered the uptake of the notion of waste in this industry.

THE COMPLEXITY OF THE CONSTRUCTION PROCESS RESULTS IN WASTE BEING A MORE COMPLEX PHENOMENON

The complexity of construction projects has been explored by many authors (among others Bertelsen 2003 and Rooke et al. 2008). It appears likely that the high complexity in construction will result in waste being a more complex phenomenon (Formoso et al. 2015). Indeed, the very complexity of construction establishes relationships that generate a complex network of chains and cycles of waste.

On the other hand, the simple and intuitive quality of the classic waste list has been essential when uniting entire manufacturing organizations in continuous improvement processes that remove waste in production. If the wastes and their interconnection are in fact more complex and less intuitive and predictable in construction, this might also explain the slow uptake of the notion of waste.

THE LOW DEGREE OF STABILITY AND REPETITIVENESS IN CONSTRUCTION FLOWS

Waste can be found both in the transformation, flow and value perspective on production (Bølviken et al. 2014). However, the concept of waste as presented by Ohno (1988) and Shingo (2005) is tightly linked to the flow perspective. They focus on waste in the product flow and in the workflow.[3] Their point of reference is manufacturing, and one of Singo's (1988 and 2005) main points is that the product flow (the flow of the product through production) should have priority over the workflow. Shingo's goal for manufacturing is a continuous one-piece flow, and he sees all deviations from this goal as waste. In this conceptualization the product is flowing through a constant production set up (factory lay out, etc.) and waste is something that can be observed in the flow. It is present over time: Buffers of intermediate products between workstations, products being processed more than necessary, workstations waiting for intermediate products, etc.

In construction, the situation is somewhat different. Here production is moving through the product. There are no permanent workstations and the physical work situation is continuously changing. Waste is therefore also constantly changing and is not necessarily observable over time. First example: A worker is waiting for a drawing and receives it after two hours. The two hours of waiting are waste and can be observed, but only in these two hours. When the drawing arrives and the worker starts working, the waste disappears. If you come back and observe the same worker at a later moment, he will be in a different location and he might be waiting for another drawing, or he might have the drawing he needs. Second example: A piece of work is not done with the proper quality and has to be remade. The working hours and the materials used to produce the insufficient quality are waste[4]. Also in this example we see that the waste is observable at one point in time, but ceases to exist when the rework is completed. Later, new quality problems might occur in other

[3] Shingo (1988 and 2005) calls these two flows processes and operations.

[4] The waste can be quantified as equal to the rework needed to establish the proper quality.

places, or they might not; and if new problems occur, they might be similar to the first quality problem, but they also might not be.

So, we find that while waste in the permanent production layout of manufacturing tends to be something that is constantly present over time, in construction waste tends to be *a parade of singular (unique), evanescent events*.

TEMPORARY ORGANIZATIONS AND A FRAGMENTED VALUE CHAIN

The produce to order logic of the project-based construction industry results in low levels of value loss in the form of products being produced but never used (Bølviken et al. 2014). However, the flipside of the coin is temporary organizations and a fragmented value chain. Often the client is the only party following the entire project, and sometimes even the client can change (e.g. when the project is sold after the development phase). Through his role in the value chain, the construction client should be seen in many ways as an integral part of the construction industry. However, many clients do not see themselves as part of the industry but, as the term indicates, as clients of the industry. Unlike many other industries, the construction industry then finds itself in the situation in which nobody takes the holistic perspective on the total value chain, including a holistic perspective on waste reduction. With the holistic perspective gone, waste reduction becomes something the individual actors in the chain have to handle alone. Reduced to local achievements, waste reduction becomes both less relevant and harder to achieve.

INTEGRATED MANAGEMENT OF INCOME, COST AND RISK

In manufacturing, product development is done with the intent to maximize profit. This implies an integrated dual perspective: the product is developed and designed to be possible to sell at a high price, and possible to produce at a low cost. With regard to production, on the other hand, the management of income and cost is typically divided. Price strategies, sales channels and marketing are the responsibility of the commercial departments of the company, whereas cost, quality and delivery on time is the responsibility of production. Thus, production is to a large degree shielded from design and commercial issues, making it possible for production management to concentrate on production alone.

In construction, as in manufacturing, project development is done with an integrated perspective on price and cost. However, in construction, design, price and cost are also managed in an integrated way in the production phase. The project organization has to manage design issues, the income side (including change orders) and the cost side (payment to suppliers, etc.). This means that the project management has to make a trade-off between how much attention is to be given to each of these different issues. While a factory manager can focus full attention on production, cost and quality, and thereby on waste, a construction project manager will in addition have to focus also on the client, the design process and the income side of the project. In total, this creates a situation where cost management and waste reduction not only appear to be, but actually are, of less overall importance for management in construction compared to management in a factory (in manufacturing). This provides part of the answer to the question raised in this paper: One of the reasons why waste reduction has not conquered construction, is that it is relatively less important for management.

DISCUSSION

Among the topics discussed, one stands out as a particularly different in comparison to the manufacturing-originated discussion on waste: construction waste tends to be *a parade of singular, evanescent events*. This raises some fundamental questions that merit to be initially commented:

1. Is the present conceptualization of waste fully relevant to this *parade of singular events*? And if not, what conceptualization would be relevant?
2. How is *making do* linked to the *parade of singular events*?

Let us start with the last question. Making do refers to starting or doing a task although not all preconditions are present (Koskela 2004). Making do is locally and at the singular point in time a rational strategy to reduce waste, the argument being that "it is better to do something than to do nothing". However, from the perspective of the production system as a whole, making do can be counterproductive and increase the negative impacts instead of reducing them. It can result in root causes not being addressed and thereby increase rather than decrease negative consequences (Bølviken et al. 2014). In other words: It is the singularity of the waste phenomena in construction that establishes the rationale behind making do as a phenomenon with a dual character, being both rational and irrational at the same time. And it is this dual character that makes making do so difficult to defeat.

Answering the first question, we find that the conceptualization of waste from manufacturing is not fully relevant for construction. Because the waste in manufacturing is present and visible over time, it can be categorized and understood directly and concretely: "This worker is waiting two hours a day", "there is always a pile of raw materials in front of this machine, etc.". Because wastes in construction are singular, often evanescent phenomena, they will have to be handled either one by one, i.e. by firefighting, or they have to be grouped into categories with similar features or similar root causes. These categories will, by their nature, have to be more abstract than the classic seven wastes (from manufacturing). Bølviken et al. (2014) categorize the wastes of construction based on the transformation-flow-value (TFV) theory of production (Koskela 2000). In the transformation perspective, waste has the form of material loss, in the flow perspective of time loss[5], and in the value perspective of value loss. Transformed to a waste reduction strategy, this would mean identifying the main material losses, time losses and value losses, and then launching improvement initiatives that address these wastes.[6]

CONCLUSION

In this paper we have identified and discussed eight reasons why waste reduction has not got off the ground in construction. These reasons show us that the explanation is not simply lack of talent or interest in the industry, but is deeply rooted both in how

[5] There can be time losses both in the product flow and in the workflow (Bølviken et al. 2014).

[6] The construction company, in which one of the authors works, has actively used the concept of working-time losses in the implementation of the Last Planner System (Ballard 2000).

we conceptualize production and management (how we see and understand the world) and in what kind of production and industry construction is (how the world is).

The aim of the paper has been to identify reasons. The next step should then be to propose implications in the form of possible actions to take. There are four possible ways to approach these actions. In regard to the explanations based on how we see and understand the world, we can either aim at changing these understandings, or we can seek actions within the present understandings. Similarly, in regard to the explanations based on how the world is, we can either accept the world as it is, and seek options within this framework, or we can try to change the world.

With the danger of oversimplifying, we consider that the solution we seek is most likely to be found by challenging the present (mainstream) understanding and, in so doing, also the fundamental features of the construction industry. Indeed, we contend that in regard to all the eight reasons, progress towards resolution has already started and has for many reasons already provided encouraging results, while initial research and development is needed for some. This is discussed next for all the eight reasons.

Construction management seen as management of contracts. As a countermeasure to this, new production control methods have emerged, based on the idea of construction management as management of production. The prime example is Last Planner System, which strengthens the production management capabilities, even across contractual borderlines.

The culture in construction. Obviously in lean, the thrust is in avoiding variability and variation instead of tackling with realized variability and variation. The Last Planner System contains many features geared towards avoiding problems and mishap. The idea of lean leadership, originating from manufacturing, similarly endeavours to switch the attention to problem avoidance.

The flow perspective understood far less than the transformation perspective. Along with the diffusion of lean philosophy and methods, education and training based on the flow perspective has recently gained foothold in construction. On the other hand, the flow perspective has been emphasized in certain methods, such as location based site management, the Last Planner System, and Takt time.

Classic list of seven wastes not fully relevant. As a countermeasure to this, construction-specific concepts of waste have been developed. The waste of making-do provides one example (Koskela 2004), the proposed understanding of waste based on the TFV theory another (Bølviken et al. 2014).

Complexity of the construction process. Here two directions can be envisaged. First, there is the argument that at least part of the perceived complexity of construction is self-inflicted through inappropriate principles and tools in use (Kenley 2005, Pennanen & Koskela 2005). The associated prescription is to simplify construction management through more appropriate principles and tools. Second, it can be argued that even if causality of waste formation is difficult to identify and predict, it could still be possible to identify patterns of waste formation (Formoso et al. 2015).

Low degree of stability and repetitiveness in construction flows. As argued above, this issue, construction waste tending to consist of evanescent phenomena forming *a parade of singular events*, would seem to be one of the most important, and simultaneously least understood hindrances for waste-based management. This conceptualization raises several questions, among others: Does the term waste have the same intuitive qualities in construction as it has in manufacturing; and if not, what terms could have the necessary intuitive qualities? Does the removal of this *parade of singular events* demand strategies other than those relevant to waste reduction in manufacturing; and if yes, what sort of strategies could they be? Here, more research and practical development are needed.

Temporary organization and a fragmented value chain. These problems have in recent years propelled many different countermeasures, such as the alliance model, public private partnerships (especially Private Finance Initiatives), and Integrated Project Delivery (IPD)**.**

Integrated management of income, cost and risk. As a countermeasure to this, the contractual models for IPD typically separate income from cost and risk management.

Construction is basically about making something. The fundamental components of this making are to decide what is to be made (development and design) and to actually do the making (production). Waste is part of production theory, but is not present in the mainstream approaches to management and economics. It is only by focusing on production and viewing management and economics as supports of this production (and not the other way around) that we can hope to get waste reduction off the ground in construction.

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ONE SIZE DOES NOT FIT ALL: RETHINKING APPROACHES TO MANAGING THE CONSTRUCTION OF MULTI-STORY APARTMENT BUILDINGS

Samuel Korb[1] and Rafael Sacks[2]

ABSTRACT

For multi-story apartment buildings, the "product" that customers value has two distinct components: shared (exterior and shared internal spaces) and private (individual apartments). The basic elements are the same (flooring, plumbing, etc.), and they are installed by the same trades using the same work methods. Yet the shared and private components are fundamentally distinct; the former entails repetitive work packages with stable design and process information, whereas the latter has high variation between products, for which information arrives in an unpredictable fashion as customers make final decisions about interior finishes. Although this dichotomy has been identified in the literature and its deleterious effects studied, construction management has ignored it and attempted to manage both project types within the same production system and by using similar management tools. In this paper, we explicate the shared/private delineation drawing on analogies from manufacturing processes (such the Mass vs. High-Mix, Low-Volume distinction) and discuss appropriate management tactics to address the inherently dual nature of the integrated final product.

KEYWORDS

Construction management theory; High-mix, low-volume (HMLV); Information stability; Product mix; Production system design.

INTRODUCTION

Application of a single uniform production system to the process of managing the construction of multi-story apartment buildings, in which each apartment is sold to a different customer, is both ubiquitous and wasteful. Customers desire to make changes to the "standard" design in order to customize the apartment to their own particular needs and budget. Many developers of projects of this type make it possible for customers to do

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so, staffing "client change departments" that work with customers to make the requested changes.

In principle, this phenomenon is very much in line with Lean thinking. Womack and Jones (2005) proposed the concept of "Lean Consumption" to reorient providers of goods and services around the needs of their customers. Among their "Principles of Lean Consumption," they state: "Provide exactly *what* the customer wants". The trend toward "mass customization" (Pine 1993) is ubiquitous in modern industry as consumers become more discerning and the number of option they can choose from multiplies apace. However, in construction, the desire to honor the requests of each particular customer leads to problems in the process of construction as traditionally managed.

BACKGROUND

Each customer makes a series of changes to the standard design, which are then translated into the blueprints or BIM model of the building, so that shop drawings for the trade subcontractors will have the correct information (Kamara et al. 2002; Rocha 2011; Sacks and Goldin 2007). The authors interviewed the manager of a "client changes office" for a construction project with 1,038 apartments arrayed in 20 buildings and obtained from them the full list of over 65,000 client changes. A large amount of variability was found in the extent of changes, as shown in Figure 1. Note that the number of apartments without changes was just 5.3% of the total.

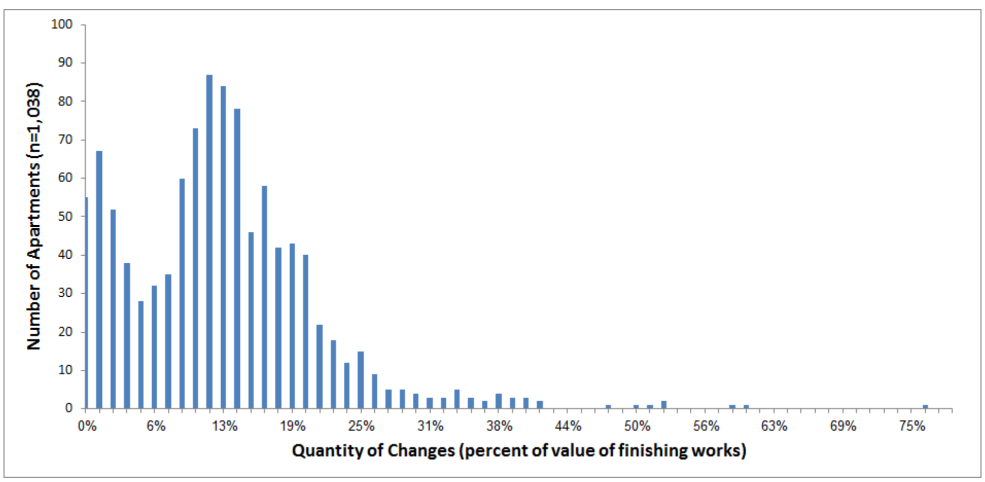


Figure 1: Histogram of quantity of customer changes in sample project.

Permitted changes to the apartment are bounded by various constraints imposed by the building design and or building codes. But within these constraints, the permitted changes are so numerous that their combination leads to effectively unbounded permutations. Some of the popular changes made in the exemplar project include adding, removing, or changing the "standard" fixtures, interior walls, materials.

While the customer changes are measured against the standard design by the client change department, during the construction phase, there effectively is no standard; the vast variety means unique shop drawings must be provided for every single apartment. Subcontractors are hard-pressed to describe exactly what the "standard" consists of.

The wide variation of configurations leads to a high level of variance of the work content for each apartment. One apartment might have many complex additions, while its neighbor has few. Shop drawings were pulled by the subcontractor on a "Just in Time" basis before beginning work on each floor. This means that the actual amount of work only became clear at a late stage in the project. Varying work content, especially when exposed late in the process, creates inefficiencies in the work as performed (Tommelein et al. 1999). Sacks and Harel (2006) described how the actors in a construction project (GC, Subs) react to variability as each seeks to maximize its own utility. Ultimately, many of these tactics lead to global inefficiencies.

Customer changes contribute to "noise" in the production system in other ways. If the customer has not made up their mind by the time the construction has progressed to their floor of the building, the information of what to build in their apartment will not be complete. This could lead to a situation in which the apartment is "skipped" with the construction progressing to the next floor, requiring backtracking in the future. A delay could also be caused by custom materials not arriving on time. Second, if the customer "changes his/her mind" once the construction is underway, rework must be performed on the apartment. The shuffling of subcontractors to make the rework happen will also negatively impact the scheduling.

The customer change processes, while intended to create more value, actually tends to create waste in the traditional construction management paradigms, in which the interior finishing works progress one floor a time up the building.

ETO, MTO, MTS Production Systems

Sharman (1984) proposed managing the supply chains of different types of products by the amount of customization offered to the customer. The point at which the customer order enters the supply chain, referred to by Sharman as the "Order Penetration" point and Hoekstra et al. (1992) as the "decoupling point", is where forecast/planning-driven production transitions to customer order-driven customization. Today it is commonly known as the Customer Order Decoupling Point (CODP), and its location separates supply chains into different types (Olhager 2010):

Make-to-stock (MTS)

Assemble-to-order (ATS)

Make-to-order (MTO)

Engineer-to-order (ETO)

The different CODPs that define the supply-chain types listed above punctuate the phases of product creation that Olhager (2010) lists: Engineer (design), Fabricate, Assemble, Deliver. In construction, the distinction between fabrication and assembly is much less distinct than assumed in other industries. Various building materials are both fabricated and assembled off-site and then brought to the construction site where another mix of fabrication and assembly ensues. Thus it is harder to delineate a construction project into the same clear "fabricate then assemble" stages. A better formulation for construction is therefore:

Engineer/Design

Off-site fabrication/assembly (to the extent that it exists in each particular project)

On-site fabrication/assembly

Deliver

Though it is not explicitly stated, it is implied in Olhager's analysis that at the CODP, the supplier receives both a commitment on the part of the customer to purchase the product as well as full information about exactly what product configuration is desired. For example, in MTS, the customer comes to the store, picks the product off the shelf, and takes it to the checkout counter. In ATO, the customer sends an order with both the desired components and information about how they will pay their bill. In multi-story apartment construction, the two components are not always received at the same time; the commitment to purchase an apartment in a new housing project can be made much earlier than when full information about design choices is supplied. For the purpose of this analysis, it is important to realize that it is the receipt of information which is critical to the construction process.

CONSTRUCTION PRODUCTION SYSTEMS

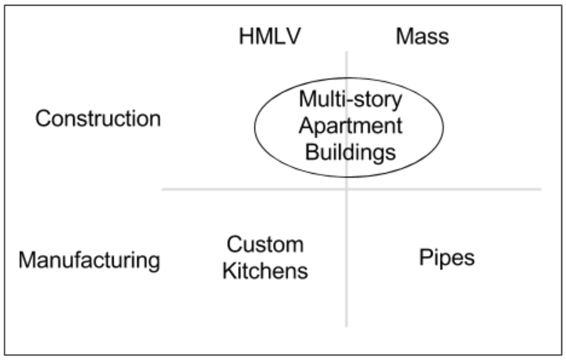
Lean Construction thinkers have given much thought to how construction relates to other forms of production (Ballard and Howell 1998; Ballard 2005; Koskela 2000). The general consensus is that though there are degrees of overlap, and even suggestions that one might be a "special case" of the other, construction is distinct from "manufacturing".

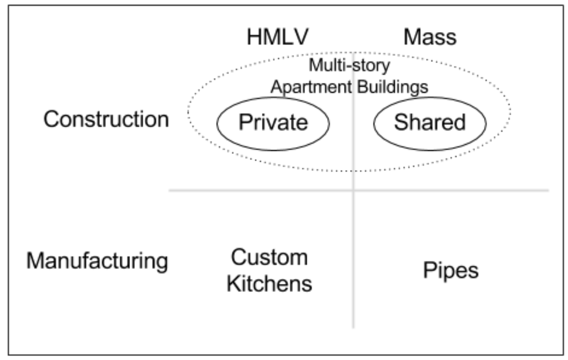
Manufacturing can be deconstructed (Schmenner 1993) on a scale from job shops that produce a wide variety of product using a mix of processes to dedicated mass manufacturing lines. The implicit level of analysis when looking at construction is at the level of the project. At this Level of Detail, construction is rightly placed closer to the one-off side of the manufacturing scale.

The authors of this paper take a different approach, suggesting a two-axis model, and drilling down to within the project itself to identify which elements can be more closely identified with which types of manufacturing. Figure 2a depicts this model, including where we identify multi-story apartment buildings to be located on these axes. Given the fact that we identify this type of project to straddle two quadrants (since the customized apartments are closer to HMLV whereas the shared elements are repeated from floor to floor), we suggest splitting the project into two, as shown in Figure 2b. This bifurcation is discussed at greater length below.

TRADITIONAL PRODUCTION SYSTEMS FOR MULTI-STORY APARTMENT BUILDINGS

The problem with the construction of customized apartments in multi-story buildings is that the process does not follow a linear "Design - Build - Deliver" progression. The customer changes represent a form of design occurring during the construction, so the progression is closer to: "Design - Build - Design again - Build some more and correct errors - Deliver". Rather than a simple linear process, there is a loop in the process from "Build" back to "Design", representing additional complexity requiring additional resources. This rework loop is a form of re-entrant flow, with the latter's attendant wastes of delays and additional costs. The unpredictable variability of the work content negatively impacts the ability to plan and execute smoothly, creating more delays.





(a) (b)

Figure 2: (a) A two-axis view of different production methods, including the location of Multi-Story Apartment Buildings in this model. (b) Splitting Multi-Story Apartment Buildings into two sub-projects.

Paulson (1976) theorized about the cost of changes to the design at different points along the timeline of a project. At the beginning, the designer has maximum influence to change the design and the costs of change are small. But as time goes by and the project progresses, more execution costs are sunk and more product is built, and the cost of change goes up exponentially at the same time that the scope of possible changes goes down. Paulson's curve has traditionally been understood as an admonishment to "front-load" the design process. In the scenario described above, design is being attempted once the project is well underway. The attendant costs are, as Paulson predicted, high. In the terminology of Sharman, both the building and apartment are Engineered-to-Order (ETO), but the engineering is scheduled to take place at two different stages.

PRODUCT TYPES IN MULTI-STORY APARTMENT BUILDINGS

The question is, "Are the inefficiencies inherent in building customized apartments in multi-story buildings an unavoidable part of the practice, or are there management tactics that can be adopted in order to improve?" We suggest the latter, in the form of an alternate production system design.

The trivial solution to the problems caused by variations in apartment configurations is to forbid customers from making any changes, and sell the standard apartments "as is" in an off-the-shelf approach (MTS). However, for a purchase as costly as an apartment, it is unrealistic to expect that customers will be satisfied with standard options. In addition, this is not in line with Womack and Jones (2005)'s Principles of Lean Consumption.

We return to the issue of information, and in particular its stability. The "product" that the end customer purchases from the developer is composed of two components that are markedly different in terms of their information stability. The first component is a shared component: the building exterior and structure, the lobbies, the parking garages, the utility mains and shared service systems. For these elements, the information is stable by the time the construction phase begins. The second component is a private component: the interior of each customer's apartment, replete with all the customizations they have chosen to turn the standard apartment into their own conception of "home." For this element, the information (across the project) is much less stable. Each customer will make their own set of changes and adaptations, which means that the project will be comprised of almost as many configurations of apartments as there are units in the building. Also, the arrival of the information adds another degree of instability, since different customers might make their choices at different times.

Table 1: Differences between the Two Sub-Components of the Productive

Feature	Building (Shared)	Apartment (Private)
Client	All customers, municipality	Single customer
Production System Type	Mass	HMLV
Variability	Low	High
Information Stability	High	Low
Location Breakdown	Multiple sets of similar locations	A single location
Location Work Content	Uniform	Unique

TWO DISTINCT AND SEPARATE PRODUCTION SYSTEMS

When viewed through this information-stability-based lens, the differentiation between the shared and the private is stark: the shared component bears resemblance to a "mass manufactured" product; the private component is more like a "high-mix, low-volume" (HMLV) product. Industrial engineers recognize that mass-manufacturing production lines must be managed very differently from HMLV job shops. Thus we propose that in construction, the project be split into two sub-projects, with the two sub-components managed separately. The first sub-project is focused on the shared components of the product - exterior, common systems, shared spaces like lobbies. The second (really a series of smaller sub-projects) is focused on building the private components of the product - each apartment's individual interior.

This rationalization will allow each sub-project to be managed in a production system tailored to its particular characteristics, rather than trying to force two dissimilar products through the same management pipeline.

WHOLE BUILDING PRODUCTION SYSTEM (SHARED SUB-COMPONENT)

The first sub-project, the shared components, is characterized primarily by the stability of the information. The work content on each floor (barring radical shifts in cross-sectional area of the building, which are less typical in multi-story apartment buildings) is similar, since the exterior structure and the lobbies and systems are "copy-paste" one on top of the other. This informational stability and repetitiveness are reminiscent of mass-produced products made in a factory, and appropriate management tactics can be adopted from this field. Takt-time planning (including work balancing) and the Line of Balance method of planning and production control are very much relevant for the shared components of the product, since the repetitiveness of the work packages lend themselves readily to line balancing and remedial measures if deviations are detected. Likewise, from a Lean point of view, the repetition of work content is very much suited to Kaizen continuous improvement, as there are both repeated opportunities from floor to floor to identify the wastes and attendant opportunities for improvement, as well as the possibility to measure the impact of the countermeasures in ensuing floors.

APARTMENT PRODUCTION SYSTEM (PRIVATE SUB-COMPONENT)

The second sub-project, the particular apartments, has little information stability, both when viewed across the project and chronologically. Work content in each apartment varies in accordance with the fancies of each individual customer, and it is very possible that the order that each finalizes their decision does not follow the orderly floor-after-floor progression that the structure is constructed in. In fact, it is entirely possible that some of the apartments will not be sold before the construction of the structure concludes; in that situation, building a "standard" MTS apartment also does not create the maximum value for the end-customer who might desire a completely different configuration. Given these instabilities and the costs associated with changing the design late in the construction process, we propose that the construction be commenced only after the information for each apartment is stabilized - that is, only after the customer has made up his/her mind. In this we continue the approach of Sacks and Goldin (2007) and Sacks et al. (2007), who showed the wastes caused by "pushing" apartments into construction before their information is made ready, instead recommending an approach more closely aligned with the Last Planner System (Ballard 2000), which seeks to shield work crews from work packages with unfulfilled prerequisites including design information, and in this way deal with the variation and variability inherent in this sub-component.

Drawing the parallel to traditional manufacturing for the private sub-component of the product, we see it is a HMLV product. The vast number of possible apartment configurations means that the variety (mix) will be high, while the number produced of each type (production volume) will be low. In an HMLV environment like a job-shop that is capable of making a wide variety of products, there is very little repetition, so the Lean principles and techniques have to be adapted appropriately. Lane (2007) and Duggan (2013) have written extensively on Lean tactics in HMLV, and many, like use of Visual Management tools to manage the information flow for the construction process and Value Stream Mapping for common/representative processes, will be familiar to Lean practitioners.

ADVANTAGES

This deconstruction of the project into two allows optimization of each individually in accordance with its own particular characteristics. The shared component can proceed apace without having to try to deal with the variation and instability introduced by the private components; the latter can be commenced only after all preconditions are met (including having the particular materials the customer has requested on hand), rather than being pressured to start according to the progression of the structure, since premature work commencement is a recipe for rework. With all prerequisites ticked off, the apartment can be completed rapidly and smoothly.

Interestingly, though the two sub-projects are distinct in the ways described above, they are both Engineer-to-Order. What the division does is allow each fulfilment stream to be properly conducted as such: concluding the design phase before beginning the fabrication, on its own timeline. And it is expected that each component will be able to shrink its lead time, which will allow a time-based competitive strategy in the market (Suri 2010). The shared component is to be tasked with a clear goal: attaining a certificate of occupancy as quickly as possible. Any delay of the shared components of the building is a delay for all of the customers together. The private components are also charged with putting an emphasis on timing; preparing all prerequisites so that no time is wasted on waiting once the work is begun. Multi-skilled teams of subcontractors (Sacks and Goldin 2007) who can jointly complete all of the work on the apartment will further simplify the management of many different apartments while reducing the lead time of each apartment.

CHALLENGES

In order to realize this approach, it is likely that various engineering and bureaucratic hurdles will have to be overcome. On the technological side, it may be possible to draw inspiration from the standardized interfaces between the "infill" and "support" of the Open Building system (Habraken and Valkenburg 1999). Another challenge may be creating the organizational structures necessary to support this new way of constructing. Presumably, as soon as the "shared" parts of the building are completed, many of the customers will want their apartments to be constructed as soon as possible thereafter. This calls for a large number of workers to perform these finishing works. Large peaks in production volume are a form of *mura* or "unevenness" (Womack 2013 pp. 107–109), and represent a form of waste in the Lean paradigm. One way of dealing with them while still meeting the customer requirements would be to "zoom out" from the scope of one particular project, and take a regional/national view of the construction industry in total, aggregating many projects together (Bertelsen and Sacks 2007). A company that could provide apartment finishing services to many different buildings could possibly have the production capacity to deploy in rapidly completing many apartments simultaneously in one building before transferring the workforce to the next building. This would allow the reduction of *mura* while still "provid[ing] what's wanted where it's wanted exactly *when* it's wanted" (Womack and Jones 2005). This hypothetical "apartment provider" could utilize a logistics center that serves both as a cross-docking location between material suppliers and containers filled with all of the material for each individual apartment as well as a "design center" where the customer arrives to choose among various materials and fixtures while finalizing the apartment layout. This latter function would be similar to the "one stop sales center" pioneered by the Doyle Wilson Homebuilder company described in Womack and Jones (2003 p. 29).

An implication of this new organizational structure is that the "apartment supplier" is no longer limited to new construction: the same supplier could provide a "gut and refurbish" service to owners of apartments in existing buildings. Further, the same supplier could provide apartments to buildings for which the shared sub-component is built by a competitor; the bifurcation of the product into two sub-components allows the customer to choose the supplier of each sub-component separately to reflect his/her particular needs.

CONCLUSION

There is a clear dichotomy between the two sub-components of the product, the shared and the private in the context of a multi-story apartment building. An analysis of variability and the timing of information reveals significant differences between these two. The logical conclusion, given the differences identified, is to separate the production approaches for the two subcomponents, instead providing production systems tailored for each type of sub-product.

This research is limited to construction projects that share the one-to-many relationship between the built project and customer base. A limitation to future implementation is that the resulting systems require deep changes to the commercial alignment of the industry. The production system alternatives developed will need thorough testing, either in simulation or field experiments.

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EVALUATION OF CONTINUOUS IMPROVEMENT PROGRAMMES

Miron, L.[1], Talebi, S.[2], Koskela, L.[3], and Tezel, A.[4]

ABSTRACT

The study began with the problem posed by an organisation for a group of researchers in the UK. There was a need to carry out an in-depth study to evaluate the continuous improvement programmes in the context of Lean Construction, and the following question emerged: How to evaluate the continuous improvement programme? This paper aims to understand how the literature on continuous improvement, including quality circles (QCs), small group activities (SGAs), and continuous improvement cells (CICs), can help to conduct the evaluation of continuous improvement programmes. The paper includes a literature review to gain an understanding of the problem from a theoretical perspective. Continuous improvement techniques are assessed in the framework of the TFV theory, with the main focus on the flow and the waste concepts. A logic model framework is used to synthesize the literature review findings and to establish an initial proposal for the evaluation of continuous improvement programmes in the Lean Construction context. This paper does not include any empirical study or actual measure and cannot ascertain the definitive benefits of continuous improvement techniques. Also, the paper does not propose any definitive procedure on how to evaluate continuous improvement techniques.

KEYWORDS

Quality Circle, Small Group Activities, Continuous Improvement Cells, Evaluation.

INTRODUCTION

The study began with the problem posed by an organisation for a group of researchers in the UK. Within a Lean Construction culture, CICs have been deployed in various parts of the organisation since the early 2014. The purpose of this deployment was to improve productivity and to create time savings. Therefore, it is necessary to carry out an in-depth study to evaluate the mentioned continuous improvement programme. From this context of a practical problem, the following question emerged: how to evaluate continuous improvement programmes?

CICs are a continuous improvement technique originated from the concept of QCs, and their derivative methods SGAs. To throw light on the continuous improvement

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programmes in the Lean Construction context, it is useful to identify the knowledge, challenges and implications in relation to QCs, SGAs and the CIC technique. Thus, this study uses a literature review to understand how the findings on continuous improvement (QCs, SGAs and CICs) and Lean Construction can help to conduct the evaluation of continuous improvement programmes. A logic model framework is proposed to synthesize the literature review findings and to establish an initial plan for the evaluation of continuous improvement techniques such as CICs from the Lean Construction perspective. This research does not include any empirical field study and does not propose any definitive procedure on how to evaluate continuous improvement techniques.

EMERGENCE OF QUALITY CIRCLES

First QCs were registered with the Union of Japanese Scientists and Engineers (JUSE) in May 1962 (King and Tan 1986) based on organisational research initially formulated in the United States (Dale 1984). JUSE established a special organisation to promote and coordinate the activities related to QCs (King and Tan 1986). QC is a form of employee involvement and can be defined as a group of between three to twelve workers who do the same or similar work and meet regularly under the leadership of their own supervisor in order to identify work related problems, analyse solutions, and where possible, implement the solutions to solve the problems (Dale 1984; Hutchins 1985).

QCs were successfully used in Japan and recognised as a significant contributor to the country's economic growth after the Second World War (Hunt 1984). QCs were primarily developed to improve the quality of the product, process, or service that the group provides (Hutchins 1985), to educate the workforce in the period of labour shortage, and to enhance the productivity (Wood et al. 1983). The ultimate goal of QC in Japan was perfection, which means it is always possible for organisations to continuously improve their performance (Hutchins 1985).

In regard to definition of quality in Western Countries, Quality Control is about establishment of sophisticated measures to plan and inspect the activities, while Japanese highly emphasise on involvement of people to train them and develop their skills. The practical outcome of the latter definition reflects in co-ordinated activities of QCs (Hutchins, 1985, p. 14) and recently CICs, which all come under the concept of SGAs.

In response to the falling productivity in the US in the 1970s, QCs were exported to the US and were primarily deployed by large corporations such as Lockheed Missile and Space Company (Ebrahimpour and Ansari 1988). After their deployment, QCs in the US were modified in many ways because countries have different concerns for SGAs. The western version of QCs has moved towards the improvement of human relations, interpersonal communications and quality of workplace (Hodson et al. 1990). The problem with the western version is that it may result in an overemphasis on the anthropological aspects and neglect the Quality Control capabilities of SGAs (Wood et al. 1983).

QCs were registered in the UK around 1977 by a few companies, including Rolls-Royce, Mullards and ITT. The interest in QC grew very fast; in 1982, an organisation, the

National Society of QCs (NSQC), was formed and it flourished for few years with the aim of promoting the QCs in the UK (Dale and Hayward 1984).

In spite of the number of books, journals, conference papers, and reports published on the QC concept in the 1980s and early 1990s, the enthusiasm for this subject gradually diminished and there is little evidence on this topic that shows this technique is still deployed. The NSQC organisation in the UK also could not survive after few years due to financial problems.

CIC is a technique that has recently emerged in the UK, especially in the context of Lean Construction, and it is a developed form of SGAs and QCs. Virtually all continuous improvement methods, techniques and practices from SGAs and QCs are adoptable to CICs. It is very important to use the existing knowledge to disseminate these techniques to more organisations.

IMPLICATIONS OF QUALITY CIRCLES

QC was claimed to be the most effective technique for productivity improvement, cost savings, and work quality improvement (Wood et al. 1983). It provides a platform to enable an organisation to take advantage of the creative intelligence of their employees (Rafaeli 1985). It is important to determine objectives and expected benefits prior to the deployment of QCs and similar SGAs and plan the evaluation programme based on them (Sherwood et al. 1985).

The most frequently stated objectives of QCs in literature are as follow: (a) reduce errors and enhance quality of products, (b) inspire more effective teamwork and job involvement, (c) improve company communication, (d) promote a problem solving capability, (e) create an attitude of "right first- time" and problem prevention, (f) develop effective relationships between management and workers (Hunt 1984), and (g) increase employee motivation (Rafaeli 1985).

Several benefits have been listed for QCs, including greater output, lower cost, improved communication and harmony in the work environment (Hunt 1984), higher work moral, motivation, reduction in conflict (Wood et al. 1983), financial survival and growth, confidence and certainty among employees that their organisation will be successful, and increased level of quality consciousness amongst employees (Dale and Lees 1987).

Regarding the quantitative benefits, Hutchins (1985) claims that QCs in Japan contribute 16% of the total profit of manufacturing companies, and that they are responsible for 25% of the profits in one large company. Hence, QCs have a great potential in cost savings and require greater attention. However, the author does not explain the methodology by which he could measure those benefits and he also does not determine in what stage of the deployment QCs could contribute to profit margins of companies. Indeed, according to Howard (1986), the benefits of SGAs are neither quantifiable nor certain.

All these expected benefits from QCs are based on following assumptions: (1) groups outperform individual members in performing tasks, identifying problems, and finding solutions, (2) teamwork and participation improve the productivity of organisations, (3) Western employees prefer workplace participation (Ferris and Wagner 1985), and (4) goal setting, feedback, and communication of skills are integral parts of performance improvement (Wood et al. 1983). Table 1 explains these assumptions further.

Table 1: Techniques and benefits of QCs

Factors	Description
Job Enrichment	QCs have the potential to enrich the work group environment by: (1) training employees, and (2) involving the workers in decision making processes (Rafaeli 1985). Job enrichment is reflected in indicators of high skill variety, task identity, and task significance (Wood et al. 1983). Increasing the role of employees in planning provides workers with greater autonomy (Rafaeli 1985) and the opportunity to work on more meaningful tasks (Wood et al. 1983)
Problem-Solving Skills	Development of problem-solving techniques among employees enables the members to properly identify and define the errors and often is one of the main sources of cost-savings (Wood et al. 1983)
Goal Setting and Feedback	Circles need to set their goals because in this way members are motivated to increase their performance. Members can then get feedback constantly on their performance outcome because their performance level must be regularly presented in graphs or tables. Performance problems can be identified in discussions with the members and level of task understanding increases (Wood et al. 1983).
Participation and Teamwork	Greater involvement in the work and management are the rewards to the employees after the deployment of QC which intrinsically enhances the motivation among the employees (Hunt 1984; Rafaeli 1985) and enables the employees to be involved in decision making process in areas where they are more knowledgeable than others (Rafaeli 1985).
Organisation Level Communications	QCs increase the interaction between the members of each circle by group discussion and team work (Rafaeli 1985). This aspect of QC provides opportunity for group members to utilise their latent skills and increases their perceived level of expertise (Wood et al.1983) by communicating and exchanging their skills.

EVALUATION OF QUALITY CIRCLES

Proof of the effectiveness of QCs requires a planned and systematic evaluation. The outcome of such a systematic evaluation programme will be hard proof for the benefits of QCs for senior managers in order to make decision about the introduction, organising, continuation, expansion, or discontinuation of deployed programmes. Academics also will benefit from the results to bridge the existing gaps by: (1) providing credible evidence on effectiveness of QCs, and (2) obtaining knowledge on circumstances in which QCs succeed or fail (Sherwood et al. 1985).

Evaluation of the full benefits of SGAs is impossible, due to the complex characteristics of human beings, and effectiveness of such programmes can be measured only partially and in long term (Sherwood et al. 1985). Cox (1981) goes further and argues that the emphasis on objective measurements must be replaced with subjective measurements by using more intangible criteria such as changes in attitudes on the shop floor and in the rest of the organisation (Cox 1981).

In order to avoid faddism, a proper evaluation mechanism must be built for programmes related to SGAs (Wood et al. 1983). A consistent evaluation from the beginning of the implementation helps managers to modify existing programmes, to convince managers to deploy and continue such programmes (Wood et al. 1983), to convince workers to continue such programmes, and to justify funds from senior managers (Sherwood et al. 1985). Overall, the impacts of SGAs can be measured on the basis of tangible and intangible effects. Table 2 and 3 present a non-exhaustive list of those effects and their related indicators.

Table 2: Tangible and intangible benefits (adapted from Wood et al. 1983; Hunt 1984)

	Effects	Indicators
Tangible benefits	**Product quality**	Reject rates, Defect rate, Client evaluation
	Job involvement and interests	Number of employee suggestions
	Attrition	Number of people terminating employment
	Worker Morale	Satisfaction with supervision/co-workers/work content/organisation/SGAs
	Management assessment	Subjective opinion of managers
	Attendance	Absenteeism, Turnover, Attendance at meetings in SGAs
	Behaviour	Number of concepts and skills learned are applied on the job
Intangible benefits	**Productivity**	Group/departmental/individual performance rates
	Cost savings	Material/labour costs, Machine maintenance costs, Wastage costs

CHALLENGES IN EVALUATION OF QUALITY CIRCLES

New management techniques or concepts are always exposed to faddism, particularly if they are originally imported. To avoid this situation, organisations must be aware of the underlying reasons, which may cause or contribute to failure (Dale and Hayward 1984). From the literature review, the challenges in evaluation of QCs are compiled in Table 3.

CONTINUOUS IMPROVEMENT AND LEAN CONSTRUCTION

Continuous improvement (Kaizen) has a strong influence on Lean Construction. Since the initial efforts of the International Group for Lean Construction (IGLC), founded in 1993, the continuous improvement concept is present as principles and approaches. In "Application of the New Production Philosophy to Construction" by Koskela (1992), many of the eleven principles proposed were realised in the framework of continuous improvement. Particularly, the ninth principle states: "build continuous improvement into the process" (Koskela 1992). According to the author, the effort to reduce waste and to increase value is an internal, incremental, and iterative activity that can and must be carried out continuously in an organisation (Koskela 1992).

Table 3: Challenges in evaluation of Quality Circles

Factors	Description
Necessity of Quantitative Evaluations	Originally, the SGAs were not measures to save costs but they intended to develop the human resources. It was believed that monetary (tangible) benefits would follow. However, over time, it became apparent that ideology and philosophy are not sufficient to guarantee the vitality of SGAs and it is essential to examine the cost-effectiveness of such programmes (Turban and Kamin 1984).
Mechanism for Evaluation and Feedback	Lack of a proper mechanism for evaluation and feedback may result in failure of SMGs. It is important to know the savings-to cost ratios, before-and-after comparisons on employee turnover and attitudes, and how the programme is functioning (Dale and Hayward 1984)
Programme Justification	The continuation or expansion of SGAs needs evaluation to be justified. Especially, if head manager is financially supporting the programme, and he is initially less committed to it (Dale and Hayward 1984)
Individual Performance vs Group Performance	Personnel may think that their performance cannot be measured as they work in groups and they may reduce their level of performance, which is likely to reduce aggregate performance. So evaluation of member performance is also important (Ferris and Wagner 1985)
Return on Investment Over The Time	New programmes initially may lead to a spurt in moral and performance. Once the programme becomes institutionalised, the longer run contribution may gradually diminish and it may even become cost ineffective in some periods (Wood et al. 1983) . Contrary, SGAs may not be cost effective in early times which may result in disbanding the programme. Wood et al. (1983) believe that before-and-after measures of multiple indicators and comparison with groups not deploying SGAs are essential to reach valid conclusions.
Short-Term vs Long-Term Benefits	Managers often tend to receive monetary benefits in short-term. The tendency of "*short-run pay back myopia*" may reduce the ability to develop human resources (Steel and Shane 1986).
The Context of the SGAs	When evaluating the effects of SGAs, it is difficult to distinguish between improvements caused by SGAs and other changes in the organisation (Sherwood et al. 1985).
The Responsible for Evaluation	There are two types of evaluators on the basis of their value stance: the "*technician-employee*" evaluator and "*scholar-scientist*" evaluator. Technician-employee is one of the members and it is very likely that he would be under pressure to produce a favourable evaluation and avoid any radical assessment of the situation. The scholar-scientist is often from outside the organisation and tries to be as objective as possible. However, if he wouldn't fully understand the scope and purpose of evaluation, he may not be able to produce results that groups and organisations need to make decisions (Joyce 1980). Thus, it is needed "*to define a role for the evaluators which is midway between that of scholar-scientist and technician-employee.*"
Emphasises on Type of Evaluation	Evaluator must have an open mind to decide on what research strategies are most appropriate to be selected for the programme in question. The primary concern should not be on methodological issues such as quantitative versus qualitative approaches or experimental design versus systems analysis (Joyce 1980).

Additionally, that publication describes some approaches for institutionalising continuous improvement (Koskela, 1992): "*(1) Measuring and monitoring improvement; (2) Setting stretch targets (e.g. for inventory elimination or cycle time reduction), by means of which problems are unearthed and their solutions are stimulated; (3) Giving responsibility for improvement to all employees; a steady improvement from every organisational unit should be required and rewarded; (4) Using standard procedures as hypotheses of best practice, to be constantly challenged by better ways; (5) Linking improvement to control: improvement should be aimed at the current control constraints and problems of the process. The goal is to eliminate the root of problems rather than to cope with their effects.*"

In the TFV (Transformation, Flow, Value) theory (Koskela 2000), continuous improvement is discussed mainly within the field of flow management. The focus is on variability elimination and perfection, which is the construct used in this study. The improvement is supported by performance measurement focusing on various types of waste. In this way, the studies on workflow measurement (Kalsaas 2013; Kalsaas et al. 2014) and performance measuring benchmarking (Alarcon and Serpell 1996; Ramirez et al. 2003) have been developed.

The CIC mechanism continues the way QCs perform emphasizing the visual management, flow and waste concepts (from TFV theory). CICs use a board acting as a nucleus for organisations, which enables visual management to establish a common ground between work groups, managers, and stakeholders. It seeks continuous improvement by measuring, monitoring and reviewing team performance.

EVALUATION OF CONTINUOUS IMPROVEMENT PROGRAMMES

A summary of some concepts around CIC including required activities to deploy them and the outputs is illustrated in a logic model (Table 4). In fact, every proposed evaluation should start with the logic model (Frechtling, 2002). A logic model is a systematic and visual way to (1) explain the current situation, and (2) present the understanding of the relationships between the inputs, which are to operate the programme, the planned activities, and outputs, which are to be achieved in short, medium and long term (Kellogg Foundation 2004).

Table 4: Logic Model for the deployment of CIC

SITUATION	INPUTS	ACTIVITIES	SHORT TERM OUTPUTS	MIDIUM TERM OUTPUTS	LONG TERM OUTPUTS
• The communication and collaboration between work groups and stakeholders need improvement • There is a strategic need to establish time savings and increase productivity	• "*Technician-employee*" evaluator (internal evaluator) and/or "*scholar-scientist*" evaluator (external evaluator) • Organisation's commitment to deploy CIC in various parts of the business • Funding	• Work groups develop their own boards • Work groups begin to hold regular meetings • Work groups are trained by a facilitator on how to deploy CIC	• Work groups have transparency of work • Collaboration, teamwork, and commitment amongst work group members increase • Interpersonal relationships and a collaborative working environment are developed • Work group objectives and milestones are set in early stage • Work groups identify interdependencies, activities sequence, front-end requirements, and their task-related risks and opportunities at the early stages • Members of work groups have equal opportunity to raise any issues • Two-way responsibility and accountability are promoted • Work groups identify the bottlenecks/enablers on the boards so all the work groups are clear and aligned • Core stakeholders engage in early stages	• Flow and performance of work groups improve • Communication and clarity of goals improve • Work groups start to remove/fix bottlenecks and constraints • Measurements help work groups to get better overview of their performance • Work groups and stakeholders that all have different disciplines engage early to collaboratively set medium to long ahead plans and milestones • Effective relationships between management and members are established • Motivation and moral amongst members is increased • Conflicts are reduced	• Work groups from different disciplines work together for the good of the organisation • Team spirit and collaborative behaviour amongst work groups are built and improved • The new trusting work environment allows members of work groups to collaborate and negotiate with each other in a proactive and productive way • Learning and continuous improvement environment is created • knowledge transfer is facilitated • Work groups spend more time on measurement of their performance and improvement activities • Attitude of "right first- time" and problem prevention is created amongst work groups • Organisational will financially grow

Evaluation programmes can be defined as a systematic operation of varying complexity, which involve data collection and analysis. They eventually lead to an effective judgment using the entirety, or some of the components of the programme being evaluated (Mizikaci 2006). In evaluation of programmes, it is crucial to define the baseline and determine to what extent (short, medium and long term) improved outcomes are important in comparison to the baseline.

The logic model can be considered as an initial common ground for stakeholders. It describes the sequence of related events for the evaluation of continuous improvement programmes within the Lean Construction context. It is important to adjust approaches in a logic model as the programme moves forward and the plans are developed (Kellogg

Foundation 2004). These characteristics make the logical model lined up to continuous improvement approaches. Thus, the logical model is a suitable method for the evaluation of programmes consisting of SGAs, QCs and CICs.

CONCLUSIONS

Continuous improvement has had a strong influence on many of the Lean Construction principles. The Lean community's efforts on continuous improvement have been focused on the management of flows and reducing waste. However, there is still a knowledge gap on the improvement concept and the evaluation of continuous improvement programmes.

CIC is a continuous improvement technique originated from the concept of SGAs and QCs. The QC, SGA and CIC techniques present challenges for their evaluation such as: (1) necessity of quantitative evaluations; (2) mechanism for evaluation and feedback; (3) programme justification; (4) individual performance versus group performance; (5) return on investment over time; (6) short-term versus long-term benefits; (7) the context of SGAs or CICs; (8) choice of the responsible party for evaluation; (9) choice of the type of evaluation. Additionally, the tangible and intangible benefits of QCs indicate some measurements that can be used in continuous improvement programmes.

In this situation, the logic model framework of evaluation seems to be suitable for continuous improvement programmes (including CICs, SGAs and QCs). The logic model establishes an initial roadmap for stakeholders and researchers to carry out the evaluation of continuous improvement programmes. Indeed, a logic model was used to synthesise the literature review findings and to establish an initial proposal for the evaluation of continuous improvement programmes of an organisation within the Lean Construction context. All in all, research on continuous improvement evaluation promises scientific and practical knowledge worth pursuing.

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DELIVERING PROJECTS IN A DIGITAL WORLD

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ABSTRACT

A 2004 National Institute of Science and Technology study estimated that the value wasted in developing traditional analog construction documents with non-interoperable information is 40% to 60% of all design cost, or almost $16 billion per year in the US alone. So, if design processes in A&E firms are digital, and modern constructors have adopted digital modeling as an integral component of their construction management, why are projects still delivered from design to construction using traditional analog information? The purpose of this paper is to identify some of the professional and organizational barriers to implementation of Digital Project Delivery. Digital Project Delivery is, for the focus of this paper, defined as the legal transfer of all project information necessary to construct a project across the design/construction interface with a minimum of analog documents as the primary deliverable. This paper consists of first-hand observations of professional engineers who have practiced on projects where the delivery was digital, primarily design-build transportation projects where the constructor and designer are tightly coupled. A limitation is that these observations were not the result of controlled study, nor are they a cross section of the entire built environment. However, these observations are consistent enough to suggest that Digital Project Delivery would result in a reduction of the cost of producing and communicating non-interoperable information, an improvement of project quality through reduced errors and omissions, and improved morale due to higher reliability and usability of project information, all key components of Lean Construction.

KEYWORDS

Digital, Delivery, Information, BIM, CIM, VDC

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INTRODUCTION

This paper focuses on examples of digital delivery of capital projects from design to construction that the authors, experienced professional engineers specializing in the practice area of transportation project delivery, have personally observed. The objective of this paper is that by providing an "inside the compound perspective" of emerging digital project delivery processes, as well as their associated challenges, future research will be encouraged to focus more on the daily processes that actually deliver projects in a digital environment, in contrast to the more mainstream approach of experimentation with the latest technologies or mass surveys to agencies that build capital projects.

The authors of this paper feel, in general, that most existing research has not gone deep enough into the "mud" of innovative project delivery to authentically communicate the naturally expected chaos, confusion, and emotional resistance they have observed on these example projects, as well as other projects on which they have practiced. There is certainly no shortage of research involving Building Information Modeling (BIM) and Lean Construction. Sacks et al. (2009) discussed synergies between BIM and Lean. Tillman et al. (2015) discussed the role of BIM and Lean in the design and production of engineered-to-order items. Merschbrock and Munkvold (2012) conducted a literature review on building information modelling research and concluded that organizational areas are ripe for research. Mandojano et al. (2015) discussed the role of virtual design and construction in the context of the 8 waste types. Gerber et al. (2010) discussed advances from practice in BIM and Lean Construction. Hamdi and Leite (2012) discussed the maturity of interactions between BIM and Lean in the construction phase. Gerber et al. (2010) discussed how BIM and Lean could be used to support the entire lifecycle of a building. There are dozens (perhaps even hundreds) of additional papers, thesis, dissertations, and even books available on this subject, far too many to address within this text. There are also a significant number of papers within the Transportation Research Board on the emerging roles of BIM, Virtual Design and Construction (VDC), Automated Machine Guidance (AMG), Civil Integrated Management (CIM) and 2D/3D combined with other attributes such as time, money, risk, safety, etc. (xD) in the design and construction of infrastructure projects.

This massive amount of research, some going as far back as twenty years, shows an intensification of activity about the potential of BIM (and other similar technologies) to support Lean goals. However, the authors feel that much of this existing research is heavily focused on the use of BIM within the confines of either the design profession or the construction industry, while research on the fundamental nature of the digital information that must cross the legal (and litigious) boundary from design to construction (whether it's in the form of BIM, CIM, VDC, xD, or any of the other cacophony of acronyms used by the AEC sector) has been generally overlooked. This boundary is most distinct in public infrastructure work delivered through the design/bid/build model. The author's positive experiences with the reduction of this boundary, or at least of the boundary's negative effects in the context of improving flow, in design-build delivery suggest an untapped opportunity for improvement on mainstream projects.

A Brief History Of Project Delivery Information Practices

Projects in the built environment, because of their spatial nature, are delivered by highly visual documents. These documents are generically known as "technical drawings". The limitation of technical drawings is not just that they are a 2D image in a 3D world, but that they are analog information in a world that is increasingly digital. In the context of this paper, analog information is anything that must be interpreted by a human being before implementation on a construction project, as opposed to digital information which is capable of being moved directly from one computer to another, even if the information requires approval by an intervening person. The use of these two terms in describing construction information is analogous to calling a slide rule an analog computer and a calculator a digital computer. Examples of analog information, whether physical or electronic, would be ink on mylar, laser toner on paper, and raster PDF's. Examples of digital information would be ASCII files, .dgn, .dwg, .dxf, .rvt, etc. It is interesting to note that digital information can exist in physical media as well as electronic. Paper tapes and punch cards predate magnetic tape and hard drives, yet still were (and hopefully are) able to effectively communicate digital information.

Our current practice methods in the creation, formatting, and reproduction of technical drawings, also known as "plans", extends back into the mid 1800's. In 1861 Alphonse Louis Poitevin, a French chemist, discovered a chemical that turns blue when exposed to light. This discovery led to the ability to produce multiple white on blue drawings, or "blueprints", from a single translucent drawing. Advancing technology eventually led to blue on white, then to black on white, then to xerographic, and most recently to drawing in the digital world of a computer with output send to pen plotters, laser printers, and even electronic PDF sheets. However, our project delivery practice methods are still rooted in the transfer of what we might call "rectangular boundaries of analog information," or drawings.

In the late 1990's to early 2000's, advanced contractors began reverse-engineering these analog drawings into digital models suited for construction, specifically for layout using "rovers" (survey instruments where the computer containing the digital model was attached to the vertical rod instead of a total station on a tripod) or AMG where Global Positioning System (GPS) or laser positioning systems are mounted on bulldozers, scrapers, or graders and combined with a computer in the cab which has the digital model. The reverse-engineering of the analog drawings was in spite of the fact that these documents were almost always created from a digital 2D or 3D model in the first place.

The introduction of design-build in the delivery of transportation projects allowed the design engineer and the constructor to be tightly coupled under the same contracting entity. This tight coupling encouraged greater flexibility in the information flow from design to construction. Design-build teams began experimenting with the transfer of the digital design information directly to construction for use in rovers and AMG equipment, with the analog documents being produced in parallel for the owners and other traditional stakeholders based on contract requirements for traditional deliverables.

A BUSINESS CASE FOR DIGITAL PROJECT DELIVERY

A 2004 report issued by the National Institute for Standards and Technology (NIST) titled "Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry" estimated that 40-60% of the time and cost of all engineering in project delivery is consumed creating, communicating, and recovering non-interoperable information. This report estimated that cost in the US at around $15 billion annually. The persistence of non-interoperable information is a legacy from the analog technologies we used in the past to deliver projects. Granted, those technologies, i.e. reproducible prints, optical survey instruments, drafting tools, etc., were the best we had at the time. However, these legacy practices consume resources without adding value. *They have ceased to add value because the technology limitations that created them no longer exist*. Capital projects can, and have, been delivered from design to construction with pure digital data while remaining fully compliant with the practice regulations issued by State boards of engineering.

In 2014, the Construction Institute (CI) of the American Society of Civil Engineers (ASCE) created a new committee for Digital Project Delivery, whose purpose is to "facilitate the transition of civil engineering practice from delivering projects in the traditional analog form of drafted plans and narrative specifications to the emerging capability of delivering projects using digital data contained in advanced models, whether 2D or 3D, and machine readable technical requirements." The Federal Highway Administration (FHWA) has also started an initiative called CIM which they define as "the technology-enabled collection, organization, managed accessibility, and the use of accurate data and information throughout the life cycle of a transportation asset."

FIRST-HAND OBSERVATIONS BY CONTRIBUTING AUTHORS

The following of examples of digital project delivery were either observed or experienced first hand by the authors:

Communication of Digital Design to Construction Year: 2005

Engineering firm "X" prepared plans and specifications for owner "Y" on a transportation project that bid at approximately $100 million. After the analog plans were delivered, both PDF and laser-printed mylar, the owner also requested a CD of the design firm's source 2D master files (Bentley Microstation .dgn), which contained all the design information that referenced into the plan sheets. After the project was bid, the owner gave a copy of this CD to the contractor without warranty, i.e. "for information only."

The contractor was digitally-capable, and brought these files into their own digital construction environment (Trimble Terramodel) for analysis. As a result of comparing the digital master files against the legal plans sheet for all of the storm drainage on the project (several hundred sheets covering about $15 million in construction) the contractor noticed that over half of the callouts were in error (callouts provide the Station and Offsets of elements that require construction, a form of curvilinear coordinate system routinely used in transportation construction) and notified the Principal of the engineering firm in confidence without formally going through the owner.

After an internal investigation within the engineering firm determined that the source of the problem was incorrect referencing of the master files into sheets causing the incorrect callouts, the principal of the firm made a personal agreement with the contractor warranting the accuracy and reliability of the master files, allowing the contractor to proceed with construction at minimal risk. The alternative would have been weeks of costly delay claims until all of the incorrect sheets were revised, printed, and channelled back through the owner's document management process for official issue to the contractor. The contractor used the engineer-warrantied digital files as input into their own digitally-driven survey and construction process, and only printed out analog sheets as needed for any subcontractors who did not have digital capability.

In the meantime, the engineering firm created new sheets with the master files correctly referenced in, created correct callouts (which were double checked this time), and issued formal revisions to the owner. By the time the revised sheets made their way through the owner's system and were issued to the contractor, the correct storm drainage system had already been laid out and actual construction was well underway.

The apparent lean principles at play in this incident appear to be: (1) defects in the original plans sheets, (2) waiting that would have occurred if the contractor was forced to wait for revised sheets, and (3) non-value added processing in the form of callouts on plans sheets that were not actually needed by the contractor, but required by the owner's legacy plans preparation standards. Allowing the contractor to build directly from the digital data is an example of efficient flow, because the information went directly from the design engineer's computer to the construction surveyor's computer.

Digital Construction Quality Assurance Year: 2008

Engineering firm "M" was a sub-consultant teaming partner to a design build Joint Venture team of Designer 'J' and construction firm 'K' contracted to deliver a project valued at $200 million. Owner "S" issued a Request for Proposals requiring the design build team to retain a quality assurance engineering firm independent of the engineering firm designing the project.

Engineering firm 'M' was brought into the proposal team as the 'Independent Quality Firm' (IQF). As the IQF, 'M' was to review the entire design, both analog plans and digital models, to verify that the design conformed to all contract requirements for design. Following this review, the IQF would be the final authority to give the traditional analog construction documents the status of 'Released for Construction' – allowing the contractor to build the facility. The IQF was also tasked with all of the inspection, sampling, and testing of the construction work to professionally verify that contract requirements for construction were being met.

From previous experience on other projects delivered through the design build model, firm 'M' knew that the task of verifying that all work conforms to contract requirements would be very labor intensive using traditional analog practices. To address this challenge, and quite frankly to improve their own profitability on a fixed price contract, firm 'M' developed a geospatial database model that was configured to allow firm 'M's engineers to identify and upload all the individual requirements listed in the contract documents. This digital approach to design review and verification provided a positive confirmation of requirement fulfilment as opposed to the traditional analog approach of "slogging" through thousands of plan sheets looking for errors or omissions – a punitive type of review. Reviewing and verifying design through a digital approach allowed for efficiencies in IQF design review staff time as well as decreasing the review schedule time.

To fulfill the IQF task of professionally verifying the quality of the constructed, firm 'M' also utilized the relational database of contract requirements. As tools to collect field data, firm 'M' procured a number of handheld high-accuracy GPS data collectors. These tools have customizable software that facilitated the collection of specific types of data complete with engineering-grade geospatial location. Field IQF staff used these tools throughout the construction day to record all field data against the design and specifications. Normally the data was measured by other instruments (such as nuclear density gauges, slump cones, air content meters, soil moisture meters, measuring tapes, smart levels, thermometers, reflectometers, turbidity meters, etc) and manually entered into the data collector to be paired with the calculated XYZ location and time of the measurement. This digital data collected at the construction site was then uploaded at the end of each day back into the main database to allow verification reports to be generated and published into the project record.

By using geospatially-enabled digital data collectors, coupled with the database of requirements, the IQF construction inspection and testing staff were able to verify significantly more construction work with fewer manhours, reducing the number of field inspection staff that would be typically assigned to a project of this size. Side benefits of this digital/requirements-management approach to construction quality management included a reduction in both the number of disputes as well as the time to review the evidence supporting monthly payment requests for work completed. Federal regulations require professional engineers to base payment approvals on a review of all the quality assurance data for completed work to verify compliance, a very time-consuming effort in the analog world. Similarly, project closeout efforts were reduced because the data used for acceptance were contained within one database that included both requirements verified and material test results.

The apparent lean principles at play here would seem to be: (1) transportation in that the field staff did not need to carry large documents in order to have all of the information needed to effectively perform quality assurance, (2) motion in that much of the data (date, time, location, user) was collected automatically by the handheld data collectors eliminating the need to constantly fill out forms, (3) waiting in that the collected data could be compared with the master design model at the end of each day, with automatic determination of any measurements not conforming to the contract requirements. If the inspectors had been equipped with the more expensive survey-grade equipment (+/- 1cm real time accuracy) instead of high accuracy mapping-grade equipment (+/- 10 cm real time accuracy and +/- 2cm post processed accuracy) the wait time for verification would have been zero.

Digital Design Development and Delivery to Construction Year: 2010

Project "X" was awarded as a $1 billion design build highway contract. Many of the project elements were designed through the use of digital files prior to construction with emphasis placed on avoiding conflicts with roadway/structural elements and utilities. The digital files assisted in developing a design that provided more confidence in avoiding conflicts in the field and led to discovering and analyzing how many of the design elements interacted. Care was taken as not all project elements were modelled. Elements such as traffic lightings and posts and overhead signing was not digitally developed as the scope of work and schedule restricted the level of detail for this project.

The digital data was brought together and used as part of a weekly design meeting between the design build team. The design consultant would post the current version of the 3D digital model to a central server. The review of the model as a group drove discussions on means and methods, phasing, and locations. Through this process, the design build team realized material and schedule savings or was able to value engineer alternative designs.

Once the digital design model was complete, the contractor would use it's own software to simulate grading or construction of project elements virtually. This served as a "sanity review" of the data and confirmed that there were no gaps in the digital model and that the necessary data had been provided to the contractor by the design consultant. Upon official receipt of the model by the contractor, the contractor directly delivered the digital data to GPS/Laser fitted construction machinery or digital survey equipment to construct project elements AMG. The owner still required a hard copy plans submittal and approval of the "analog" design, and there were no digital delivery requirements by the owner. The contractor managers chose to use digital delivery as they believed this approach significantly reduced risk and accelerated construction for this project.

The process of developing and delivering the digital files has its challenges along the way. At project initiation the project manager for the contracting team believed every element of the project would be developed in a 3D digital environment, including the smallest details. Given the scope of work for the design consultant and quick schedule associated with winning the project this was not possible. Once the project was awarded, key elements were developed at finer granularity as needed.

The largest challenge encountered in delivering digital design to construction was the compressed schedule and determining the priority of delivery for segments of the project. The project was broken into three key areas and the design team had a lead digital delivery person for each section and a fourth, lead digital delivery coordinator. As the project evolved the digital delivery team mentored others to ease the burden of workload on the digital delivery team. There were a few segment leads who were originally resistant to the development of design in a fully digital environment, but they eventually came to rely on the ability of the team to coordinate using the digital model as a means for coordination and delivery.

Another challenge was that one of the key design subconsultants (subs) was not experienced with developing a digital design model in 3D, even though they were using the same software platform as the lead design firm. The team discovered that the sub was not updating the master digital design model as the design evolved, but was keeping all of their information in the traditional legacy design environment used to create 2D analog plans. This created a situation that initially prevented digital file coordination. After multiple delays and coordination issues, the lead design firm was forced to take over and manage the digital development of these files as the project team saw the necessity and advantage the digital delivery process provided. The sub coordinated the design with the lead design firm after this discovery, and while the process was streamlined still provided challenges with every day coordination and development of the digital model

The apparent lean principles that would seem to be in play here are: (1) overproduction in that project elements were not modelled in fine granularity until that level of development was needed. Some elements were not modelled at all if it was determined that analog information delivery was more efficient, and (2) waiting in that different project teams did not need to spend time preparing traditional documents to communicate their design to the other parts of the team.

Digital Design Quality Assurance Year: 2011

Engineering firm "W" was the design firm for a $1 billion design-build transportation project under contractor "Z". While the contractor had advanced digital capability, the owner still required the submission of analog construction plans, both PDF and paper, as well as the submission of paper "check prints," or quality control prints, showing where each plan sheet had been reviewed; any errors discovered were marked in red, and all correct information highlighted in yellow. Because of the intent within the design-build team to legally transfer any complete digital design information directly to the construction surveyor, after being digitally signed according to the State Engineering Practice Act, the design quality control was implemented with a corresponding digital process.

As the design was being developed, the design quality control engineer referenced all the relevant design files and models into a separate review environment. The semi-live design was reviewed against all contract requirements and design standards and notations from these review, for both correct and incorrect features, were placed in a review file that had the same coordinate system as the 2D design files. In cases where the design review required generation of static 3D models, such as verifying that certain tie-in points had matching elevations, all notations were placed in a 3D file at the XYZ coordinate of the design feature that had been reviewed.

These review files were then referenced back into the live files being continuously developed by the design engineers where any errors or conflicts were corrected. Once the digital design files were approved and sent to the contractor, analog plans for the owner's consumption were printed from both the current set of design files as well as the pre-review file snapshots. The review files were projected on a wall in a conference room where the design engineers assisted the quality control engineer in transcribing the digital review into red and yellow marks on the printed plan sheets. This transcription process was surprisingly fast. The final paper copy and the red and yellow "Check Prints" satisfied the owner's document control requirements, even though the project was being constructed using digital data and not the plans.

The apparent lean principles at play in this incident appear to represent: (1) overprocessing in the sense that physical documents were being created only to satisfy a legacy contract requirement; (2) motion in the sense that additional work was required to create the Check Prints with no added value, and (3) batch size in the sense that the review was conducted in small increments as each part of the design was complete, rather than waiting for a large set of review prints at 30%, 60%, and 90%. The near-real-time review by the design quality control engineer offers an example of flow in the sense that the design could be reviewed as soon as it was ready without the need for additional preparation or printing. The results of the reviews were immediately available to any design engineer that needed it. The audit trail of the reviews allowed for anyone to see the progress of the design, as well as any design changes or correction, at any time period or any physical location of the proposed construction.

DISCUSSION

These examples provided by professional engineers working on projects with components of digital project delivery illustrate some of the challenges faced by practitioners. These first-hand observations are by their very nature non-random and not necessarily representative of mainstream project delivery. However, they do illustrate some of the ways that digital project delivery is possible, and some of the roadblocks faced by innovators in the way of legacy processes, policies, or contract requirements. *One of the key themes in most of these innovations is the tendency for individual practitioners to "work around" apparent flaws in the contract documents or organizational processes.*

Although technology has enabled improved practices, the legacy language in contracts may actually discourage their use, or still require an obsolete practice resulting in double work. If digital project delivery is to become mainstream in the future, the professionals in charge of project delivery will need to modernize contract documents and organizational procedures and requirements to support, or even encourage, these new capabilities. This implies the need for active involvement of lawyers, insurers, contract writers, and even politicians, not just engineers, architects, and contractors.

CONCLUSIONS OF AUTHORS

The authors of this paper hope that these examples help to communicate the potential of delivering projects digitally without the burden of analog documents and legacy contract requirements. Our intent is that these examples encourage the growth of field research by academics who are embedded on innovative projects at the lowest levels, whose primary responsibility is to identify the fundamental theories involved in the deployment of these new digital processes, as opposed to the ad-hoc sharing of first-hand experiences by licensed professionals within the confines of gatherings of practitioners.

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"RESPECT FOR PEOPLE" AND LEAN CONSTRUCTION: HAS THE BOAT BEEN MISSED?

Samuel Korb[1]

ABSTRACT

The Toyota Production System (TPS) is the powerful engine that has rocketed the Toyota Motor Company from a backwater operation in a war-torn country to the largest automobile manufacturer in the world. Lean thinking (as TPS has come to be known outside of Toyota) has been successfully applied to industries from across the spectrum of products and services, from technology start-ups to healthcare providers.

The construction industry has also been lured in by the siren song of the benefits of a successful Lean implementation: more satisfied customers, greater profitability, and improved metrics across the board. But as the International Group for Lean Construction (IGLC) celebrates its 24th annual conference and declares the field to be "on the brink of revolution," the question arises: has the promise of Lean Construction been fully realized?

Toyota has long stressed that TPS stands on two pillars: Continuous Improvement, and Respect for People. The former brings with it the hoped-for results, but it is the latter that makes the former possible. Their motto is: "We make people before we make cars." Companies that have successfully implemented Lean consistently state that their achievements would not have been possible without sustained employee engagement and support at all levels of the organization.

Have Lean Construction enthusiasts grasped the importance of the Respect for People principle? Have they recognized the crucial nature of employee engagement? Based on the literature, the answer is no.

In this paper, I examine the dearth of focus on this topic in the field, examine case studies from other industries, and discuss what "Respect for People" could look like in light of the peculiarities of how Lean construction is currently practiced.

KEYWORDS

Respect for people, Toyota Production System (TPS), Lean Construction shortcomings, construction peculiarities, IGLC, literature review

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INTRODUCTION

The collection of principles, practices, and philosophies we have come to call "Lean" (Krafcik 1988) is essentially the management system developed at the Toyota Motor Company, genericized and abstracted out to be relevant to many different business environments beyond automobile manufacturing (Jones 2014). This makes sense, since the history of "Lean" is an attempt to achieve the same stellar results and operational excellence that Toyota has enjoyed over the course of decades. There have been attempts to bring Lean to areas as diverse as start-ups (Ries 2011), healthcare (Graban 2012), software development (Poppendieck and Poppendieck 2003), accounting (Maskell et al. 2011), and of course construction (Alarcón 1997).

Yet despite the volumes published and the efforts expended, very few companies in construction (and for that matter, in any industry) have been able to achieve anything close to what Toyota has achieved. Spear and Bowen (1999) suggested that Toyota's secrets lay at the sub-cellular level, but in truth it is not necessary to go that deep to begin to understand the shortcomings of would-be Lean enthusiasts.

In 2001, Toyota was expanding so rapidly and so globally that they felt they could no longer trust their oral tradition to ensure the spread of their values and management approach to new factories and offices. They created a document known as the "Toyota Way 2001," to assist in this effort. In this document, Toyota described what it believed were the two pillars of the Toyota Way: Continuous Improvement and Respect for People (Miller 2008), as shown in Figure 1.

Figure 1: Two pillars of the Toyota Way, as expressed by Toyota: Continuous Improvement and Respect for People (Toyota Motor Corporation 2012)

Continuous Improvement (CI) is the headliner of Lean – how to use one of the many tools from the Lean toolbox to slash waste in the organization while creating more value. Nary has an "Introduction to Lean" workshop gone by without CI being heralded and its power to transform proclaimed. Respect for People (RfP), on the other hand, is the unsung of the two, typically meriting no more than perfunctory lip service before getting back to tales of inventories slashed and lead times quartered.

Yet we note from the diagram that RfP is depicted as no smaller than CI, and in truth it is no less important (Emiliani 2008). But the most important is neither the former nor the latter; it is the intersection portrayed on the graph; only the combination of CI and RfP allows the house of Lean to stand and achieve the heights desired.

Without Respect for People, Lean is only Continuous Improvement, which tends to focus very quickly on the technical side. Emiliani (2013) calls this approach "Fake Lean," while Graban (2007) refers to this as "Lean As Misguidedly Executed" (or "Lean As Mistakenly Explained", both sharing the acronym L.A.M.E.). Both of these pejorative monikers describe the situation in which management pursues a strategy of CI without including RfP, with results that are short-lived and grate upon the workforce.

The rest of this paper seeks to answer the following questions: given the importance of Respect for People, what can be said about the attention this principle has received among Lean Construction proponents? What are the barriers that could prevent RfP being more fully implemented in construction companies? And what exactly does "Respect for People" mean in the context of Lean?

LEAN CONSTRUCTION AND RESPECT FOR PEOPLE

Given the centrality of RfP as explained by Toyota, to what extent has the Lean Construction community in general and the International Group of Lean Construction in particular given it attention? It appears that the answer is "not much." A search of the IGLC proceedings[2] reveals only seventeen papers that use the phrase "respect for people" or "culture of respect"[3] (see Table 1), opposed to 451 papers dealing with "continuous improvement." The Journal of Lean Construction shows a similar disparity: no mention of "respect for people" versus 33 papers that touch upon CI.

A thorough reading of each of the papers that mention the concept reveals that they neither delve deeply into RfP as defined by Toyota nor connect the concept to Lean Construction. The articles were according to a few repeated treatments observed in the literature (see Table 1).

Some of the papers had only a passing reference to RfP; these were coded "PR".

In many of the references to RfP, the context suggests that "Respect for People" was used in a broad sense of "treating people fairly" and "creating working environments in which their lives are not threatened." While jobsite safety and not demeaning people are of course necessary conditions for RfP, this colloquial usage is not what is meant by Toyota when they use the term. Just as other Lean concepts like "waste" and "value" have very specific definitions in a Lean setting, Respect for People is not a catch-all feel-good phrase. It has meaning (discussed in the next section) and it has a purpose (Womack 2007). This was coded "CU" for colloquial usage of the term "respect."

Some of the papers did come closer to the Toyota-inspired true meaning RfP, though they failed to connect RfP to Lean Construction in a meaningful way. These were coded "NLC" for "no connection to Lean Construction."

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2 e.g. http://google.com/search?q=site%3Aiglc.net%2FPapers%20"respect%20for%20people" (accessed April 2016), which covers IGLCs 4 to 23, and the index and ToC of (Alarcón 1997), which contains the highlights of IGLCs 1-3 (a full-text search of the latter was unfortunately not practical).

3 An alternate phrasing, pioneered in the Rybkowski papers, which appears to refer to the same concept.

Despite the paucity of direct focus, there has been indirect attention given to the importance of RfP, as evidenced by the spread of two key Lean Construction tools: The Last Planner® System (LPS) (Ballard 2000) and Integrated Project Delivery (IPD) (American Institute of Architects 2007).

Table 1: References to "Respect for People" and/or "Culture of Respect" in IGLC Proceedings (paper subtitles have been omitted for brevity)

Year	Author(s)	Title	Code(s)
2004	Pasquire et al.	Off-Site Production	PR
2005	Orr	Lean Leadership in Construction	CU
2005	Pasquire et al.	What Should You Really Measure if You Want to Compare Prefabrication With Traditional Construction?	PR
2008	Court et al.	Modular Assembly in Healthcare Construction	CU
2012	Koskenvesa and Koskela	Ten Years of Last Planner in Finland	NLC
2012	Koskenvesa and Sahlstedt	What is Seen as the Best Practice of Site Management?	CU
2012	Mäki and Koskenvesa	An Examination of Safety Meetings on Construction Sites	NLC
2012	Pasquire	The 8th Flow	NLC
2012	Pekuri et al.	Applying Lean in Construction	NLC
2012	Rybkowski et al.	Survey Instrument to Facilitate Continuous Improvement of Lean Teaching Materials	CU, NLC
2013	Bettler and Lightner	Applied Leadership Model for Lean Construction	CU
2013	Rybkowski et al.	On the Back of a Cocktail Napkin	CU, NLC
2013	Tsao et al.	Teaching Lean Construction Perspectives on Theory and Practice	CU
2014	Hämäläinen et al.	Are Tools and Training Enough	CU, NLC
2014	Kpamma et al.	How Aligned Is the Competency-Based Training Model With the Lean Philosophy?	NLC
2014	Rybkowski and Kahler	Collective Kaizen and Standardization	NLC
2015	Nikolin et al.	A Call for New Research in the Lean Construction Community	CU

The success of LPS is likely due in part to its inherent combination of CI and RfP – the very act of involving subcontractors in the process of planning engages their mental skills and asks them to take an active part in improving the process of construction. Thus respect is being shown for their creative and cognitive abilities, which is key in fostering continuous improvement. IPD also highlights the importance of RfP, since it creates an atmosphere where the interests of the collaborating parties are aligned. This allows for more investment of energy in finding solutions and improvements that are beneficial for the project. By creating a win-win atmosphere, respect is indeed being shown for all stakeholders: owner, design professionals, contractors.

WHAT IS "RESPECT FOR PEOPLE"?

Up to this point, I have skirted this central question: if the examples cited above are not true RfP, what *is* Respect for People, as defined in a Lean context? And how does it mesh with and reinforce CI?

The "secret sauce" of true Lean is not the use of tools to achieve short-term, point improvements (as impressive as they may be). Rather, it is creating an organizational culture and climate in which improvements to the work methods and processes (the way the work is done) are being made every single day, by every single member of the organization, in every area of the organization. This is what Maasaki Imai, the author of the seminal works Kaizen (1986) and Gemba Kaizen (2012), is attempting to convey in his definition of the word *kaizen*: "Everyday improvement, everybody improvement, everywhere improvement." (Kaizen Institute India 2013). The most successful Lean organizations are not the ones with the largest "Kaizen Promotion Office" or the most elaborate Lean posters; true success comes from creating an organizational culture and organizational climate in which "improvement" is a daily responsibility for everyone.

For a 150-person company, this means 150 pairs of eyes actively looking for and capable of identifying wastes and the corresponding opportunities for improvement in the processes with which they are intimately familiar. It means 150 hearts knowing that their contributions will be respected and valued, and thus motivated to make those improvements; 150 brains puzzling out the wastes identified in order to develop countermeasures; and 150 pairs of hands to pick up the pieces if the planned countermeasure fails to work out and additional work is needed to improve further.

This is Respect for People as it relates to employees[4]: respecting the innate ability of every human being to identify waste and develop creative ways of improving. It means respecting their contributions and simultaneously challenging them to always be improving their problem-solving skills. It means asking people not only to put out fires but also to prevent future flare-ups from igniting. Giving them the time and resources to experiment with countermeasures, even if it means allowing the experiment to fail (albeit in a controlled manner). And it means providing the training and leadership necessary to both provide the skills to recognize waste and develop countermeasures that are in line with the company's overall objectives.

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[4] RfP in its fullest sense relates to five groups of organizational "stakeholders" in the organization: employees, owners (shareholders), customers, suppliers, and the greater community in which the organization operates. Typically companies do not suffer from a lack of respect for shareholders' interests, and much of Lean is about bringing customers to the fore. Suppliers are in many ways similar to employees as relates to RfP, though typical Lean implementations will begin "in-house" before expanding out to suppliers. For all these reasons, I have chosen to focus on employees for the bulk of this paper.

When understood in this fashion, it becomes clear why RfP is crucial to long-term Lean success: Continuous Improvement that is truly continuous and ongoing can only survive in an atmosphere where RfP is being practiced. RfP creates the fertile ground that allows CI to flourish (Liker 2011). Companies that see the true potential of Lean are those that are constantly investing in the problem solving abilities of their workforce at all levels and that make time for “Daily Kaizen” (Miller et al. 2014), thereby challenging them not only do their jobs but also be responsible for improving them (Rother 2010b).

Rother (2010a) goes so far as to claim that Lean tools are in fact no more than structured frameworks for developing people and improving their problem solving capability. Ballé and Ballé (2005, 2009, 2014) repeatedly show how a true Lean implementation is more about growing people than throwing out all the inventory in the organization or finding a few point examples of waste to remove with fanfare.

Paul Akers, the founder and president of FastCap, relates how the message of RfP finally hit home for him (Akers 2011). His company was a number of years into their Lean journey, and they had made great strides. But Akers felt that whenever he was not physically present to push the improvements along, the company made no progress. During one of his study missions to Japan, he had the opportunity to meet a VP from Lexus. Akers asked the executive to tell him what the most important thing was for Toyota. The response he received echoed the quote from the abstract of this paper: “Our number one concern is how to build our people and how to build a culture of continuous improvement.” Reinvigorated, Akers returned home to introduce RfP to a company that had been steeped only in CI up to that point. Today, FastCap employees spend the first hour of every day of work making improvements. Akers asks that they make no more than a two-second improvement each day, since he knows that it is consistency of improvement that will over time lead to a competitive advantage (*kaizen*), not a few “home runs” hit intermittently (*kaikaku*). The second hour of each day is also spent in developing people, with an all-hands stand-up meeting to review the core values and metrics as well as share improvement ideas. When other business leaders are aghast to find that two hours of every day are spent in apparently non-productive work, Akers responds: “In only six hours, my people can outperform anyone else working eight but not taking the time to improve.”

Akers is a shining exemplar, but the theme of harnessing the creative power of all employees through RfP runs through all the stories of the most successful Lean implementations.

BARRIERS TO IMPLEMENTATION IN CONSTRUCTION

The fact that the marked majority of all Lean implementations (in construction and beyond) do not succeed suggests that there are barriers to successful implementation of RfP that are not specific to construction. They include being overly enamoured with CI as well as not fully understanding RfP and/or underestimating its importance to the long-term success of Lean (Emiliani 2008).

Beyond those initial barriers, we can consider difficulties that are specific to construction, which will additionally need to be overcome for the enlightened Lean

Construction implementer. The subject of "construction peculiarities" has received much attention, with Vrijhoef and Koskela (2005) identifying three main peculiarities at the level of construction projects: site production, temporary organization, and one-of-a-kind product.

Of these, only the second is a potential barrier to RfP in Lean Construction, since the temporary nature of each project tends to cause the parties to focus on short-term outcomes and seek to optimize at the level of the project. Site production and one-of-a-kind product do not offer the same challenge, since they do not assume the same level of worker transience. As Liker (2004) has identified, the first of fourteen principles that guide the Toyota Way is "Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals." For no other area is this more relevant than RfP; making an investment into developing people and their problem solving skills requires the organizational self-discipline to maintain a degree of focus beyond the event horizon at the outer bounds of the current project. In addition, since subcontractors who are not directly employed by the GC perform the vast majority of actual work on the building, it will be an uphill battle to make the case (business or otherwise) for developing the same front-line workers who will be gone soon after their contribution to the project is complete.

WAYS FORWARD

Given the barriers identified, is there any hope for RfP in Lean Construction? Is there any light at the end of the tunnel?

First, as with any Lean implementation in any company in any industry, Lean aspirants in construction companies must begin the work within their own four walls. Even the smallest AEC company can teach all of its people to see waste and develop countermeasures to address it, while empowering them to make changes in the work processes. As Maasaki Imai pointed out in his quote above, the goal is to have everyone in the company, everywhere, making improvements every day. As Akers has shown, these need not be grandiose changes every day; an improvement by each person that shaves no more than two seconds off a process will suffice, as long as one is made every single day.

For those not yet ready to commit two hours a day for every employee, an employee suggestion program may be a more viable first step (Tozawa and Bodek 2001) . The emphases in making a program of this sort a success, and one that will reinforce RfP and CI, are small-scale changes, ones within the employee's sphere of influence, that does not necessarily require large capital outlays, for which approval to begin a trial can be rapidly granted, and that the employee is directly involved in trying out. More important than establishing financial objectives for the program is aiming to get everyone contributing, with coaching by direct managers as necessary (and not using coercion by any means). The opposite scenario, in which suggestions are placed in a locked box, reviewed infrequently by management, and implemented by a third party (typically an engineering or maintenance function), is not RfP and thus will not reinforce Lean efforts.

Tidhar Construction, a small-to-medium construction company located in Israel, has experimented with an in-house employee suggestion system, after their CEO went on a similar Lean study tour to Japan and was inspired by seeing the suggestions that had been implemented by front-line employees, as explained to the visiting group by those same employees. In the four years the program has been active, they have generated over 800 suggestions. Thus an initiative of this sort is entirely possible for a construction company.

At the same time, only so much can be done in-house (though it is possible to do quite a lot over the course of years as people grow and develop). A lot of waste may be "locked in" at the design phase, and therefore any company that only is involved with executing plans developed by others may be limited. Likewise, for GCs, their ability to impact the work methods of the subcontractors who actually perform the work may be limited. Thus a typical progression, once Lean has started to become "the way things are done" within the company, is to start reaching out to key suppliers (and in construction, subcontractors are key suppliers) and beginning to work with them to teach some of what has been learned and begin implementing in order to find mutually beneficial improvements.

Another tack entirely would be to work through local trade unions, spreading Lean thinking and Lean training horizontally through the local industry. This is what has been done in Denmark; the Federation of Building, Construction and Wood Workers Unions has embraced Lean Construction, seeking to make it the industry standard (Koch 2007). In this way, Lean understanding can diffuse horizontally rather than requiring one company to invest in what are perceived as "here-today, gone-tomorrow" subcontractors.

CONCLUSIONS

Lean neophytes do not always see how the sort of small improvements that mark RfP (particularly when they are no more than two-second improvements) can lead to the significant bottom-line improvements that Lean promises. But by building culture where every person, every day, is making a two-second improvement, larger improvements are inevitable, since people will be turned on, motivated, and experienced in problem solving by the time larger opportunities present themselves. This is Collin's "turning the flywheel" (Collins 2001) writ both on the micro (two-second inputs each time) and macro (getting to a pace of improvement that allows the organization to outpace their competition). Byrne (2013) explains how small improvements in reducing setup time (SMED) are actually a strategic move for the company: by reducing the time required to change over from one product to another (setup), it is possible to reduce the batch size of the products being produced. A reduction in batch size means that the lead-time of any given product is reduced. Thus the company will be able to respond more quickly to customer requests and changes in demand than their competitors, and gain more market share as a result. This is the essence of *kaizen*: small changes that are made consistently, accumulating over time to lead to big improvements.

In the construction sphere, despite the peculiar barriers present in the industry, it is also possible to gain a competitive edge from the sustained application of CI. But this can only happen when RfP is present, so the two must be implemented together if either is to survive. Emiliani (2015) has suggested that Respect for People is a practice that defies simple verbal definition; it must be implemented in order to have its full effect.

For researchers in the field of Lean Construction, research questions going forward include: how can Lean Construction implementations more fully utilize RfP, and what are the impacts of doing so successfully? How can construction companies overcome the limitations imposed by temporary organizations and the subcontracting model in the quest to return this second pillar to its full importance? How can construction companies make the investment in daily kaizen, given the fast pace and high-stress nature of the industry, and will they reap the same returns that other have been experienced by other companies in other industries? To what extent are the successes of LPS and IPD due to their inherent involvement of RfP?

And finally, is it possible to disprove the central claim of this paper, namely, that without RfP, CI-focused Lean Construction implementations are inherently limited in what they can achieve?

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HISTORY AND THEORETICAL FOUNDATIONS OF TAKT PLANNING AND TAKT CONTROL

Shervin Haghsheno[1], Marco Binninger[2], Janosch Dlouhy[3] and Simon Sterlike[4]

ABSTRACT

The use of Takt is one of the key methods applied in Lean Production. With the implementation of Takt into processes overproduction is prevented, lead times are reduced, and work processes are stabilized. Inventory and waiting times between work steps are reduced, transport is optimized through continuous flow and a higher production capacity is enabled.

In Germany the method of Takt Planning and Takt Control for use in construction was developed approximately ten years ago in practice. In the last years these methods have also been discussed in the international lean construction research community.

This paper brings together the development of the theoretical foundations for the use of Takt Planning and Takt Control on the basis of a literature review. Hereby the existing knowledge from the stationary production industries can be applied to the construction sector. Furthermore, practical experience gained by the authors from the application of Takt Planning and Takt Control has been incorporated. Along with the historical development of the use of Takt in production, the fundamental principles for implementation of Takt in construction processes are described. The theoretical foundations developed here provide a basis for future research to investigate the effectiveness of the use of Takt Planning and Takt Control systems.

INTRODUCTION

SCOPE OF APPLICATION OF TAKT

Takt plays an important role in music, traffic, information technology and technical procedures. Takted processes are applied in many areas of today's everyday life, and Takt is a central part of their coordination. Takt is generally the basis of musical compositions and lyrics, the march of an army and also indispensable for the crew of a row boat. Transportation systems function through takted route timetables, phone calls are invoiced based on takting and motors run on a defined basis of takted combustion. The pulse of a heart is also a form of Takt, which defines the frequency and amplitude of a heartbeat.

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Takt plays an especially important role in industrial production. When it is necessary for different fields or people to work together to an agreed speed, Takt serves as the basis of this speed.

DEFINITION OF TAKT

The origin of the term “Takt” is from the Latin “tactus” meaning “touch, sense of touch, feeling”. From this the term “to have Takt” can be derived. In the 16th century a Takt was defined in German as “durch regelmäßige Berührung ausgelöster Schlag” (EN: “beats applied through regular contact”) (www.wissen.de 2015a, 2015b). The first meaningful translation of Takt is the English term “beat”. Frandson et al. (2013) further defines that the German word ‘Takt’ refers to ‘rhythm’ or ‘cadence,’ that is, to the regularity with which something gets done. A Takt can be understood as an impulse generator, which triggers an action in uniformly sized time intervals. The application of a Takt to a process is described as takting. The timespan between two beats of a Takt is termed as Takt time. According to Frandson et al. (2013) “Takt-time is ‘the unit of time within which a product must be produced (supply rate) in order to match the rate at which that product is needed (demand) rate“.

Alongside Takt there is also rhythm. In music the rhythm (Greek: rhythmós = flow) determines the arrangement of time progression. Expressed another way, rhythm leads to a time structure, a pattern or a sequence of tones and pauses. Unlike Takt, which has a predetermined repetition of processes with the same duration, the rhythm can vary within individual Takts. In production the scope of a Takt is also defined by the product. In construction this is also the case due to the spatial aspects of a structure. Takt times are generally determined by the categorization of the structure into different spatial areas. The work content of the areas can therefore be varied. Through this a specific rhythm will occur according to the Takt and work content.

HISTORY OF TAKT IN PRODUCTION

Takted processes already played an important role in production before the industrial revolution. Records from a 16th century shipyard of an arsenal in Venice describe a stable and takted production of merchant ships and warships. Due to the high demand for ships from the Venetian state a system of continuous production was developed which was unique for its time (Das Arsenal von Venedig, 1)

At the beginning of the 20th century Takt was increasingly used in industrial operations. One of the most well-known users of Takt-based production was the automobile pioneer Henry Ford. Fascinated by the “disassembly lines” of Chicago slaughterhouses, in Detroit in 1913, Ford was the first company to introduce mass production of automobiles using production lines. Through using the production line, production capacity was increased on the one hand, and on the other hand it was possible to use unskilled labor rather than a specialized workforce. Built this way, the Model T Ford was able to be assembled faster and cheaper than similar cars built at this time. (3sat 2014).

In other industries Takt was used for the first time in the German aviation industry. Takt was used as a precise time interval to synchronize the movement of airframes through a production facility. At the end of every Takt the airframes were moved to the next step in the assembly (Womack 2015). Technical cooperation between the German aviation industry and Mitsubishi brought this idea to Japan where Toyota took Takt and incorporated this approach into the Toyota Production System (TPS) (www.lean.org 2015).

James P. Womack and Daniel T. Jones described the TPS and significant approaches of other low-waste production systems in their books "The Machine that changed the world" (1990) and "Lean Thinking" (1996). Through these works they introduced the term "Lean". Takt time was mentioned by Womack and Jones (1996) and brought into connection with the principles flow and pull. The significance of this in TPS was however not mentioned. Takt was considered as a tool aiding the reaching the basic principles of lean thinking. However in practical applications takt is a central element of production systems. The Toyota Production System and most other production systems for automotive assembly state takt as one of the integral parts of their system.

THE ROLE OF TAKT IN PRODUCTION SYTEMS

In the meantime almost every large enterprise in the automotive industry has based their own production system on lean principles. In most cases the production system is visually represented with sketches or diagrams. In many production systems, for example Porsche, BMW, Daimler and Toyota, Takt plays an important role and is shown in these representations. Figure 1 shows a representation of the Toyota Production System, the most well-known example of this system.

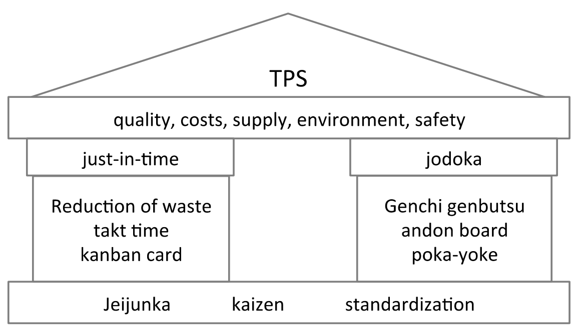

Figure 1: The Toyota Production System (Toyota 2010, 5)

Takt time is a central element of the just-in-time pillar of this production system. In industry Takt time is commonly defined in minutes. For example Porsche sets a Takt of approximately five minutes as the market on average absorbs one car every five minutes (Friedrich 2013, 48). The potential influence Takt can have on a production system is highlighted in the example of the Wolfensberger foundry in Germany. The introduction of one piece flow led to implementation of takting and equalization of the duration of the working steps. The new takting enabled throughput times to be reduced by 50% (Reusser 2013).

From a company perspective, the selection of a Takt time is dependent on the product. From a lean perspective the customer stands at the center. Hopp and Spearmann (2008,

495) define this approach as the demand rate. The Takt and the batch size selected define the output. This means Takt is a means of satisfying customer demand.

CALCULATING A TAKT IN THE STATIONARY INDUSTRY

Takt has the goal of fully meeting customer demand. It is the time interval in which a quantity is produced and thereby also defines the procurement and purchase rates (Frandson et al. 2013). In this way the market influences the Takt.

$$customer\ takt\ *\ batch\ size = \ Output$$

Therefore takt is defined as the time interval in which the quantity of a product variant is produced with regard to the available process time (Lean Production Expert 2012). The customer takt is the time to produce one batch:

$$Customer\ takt\ (production) = \frac{available\ net\ working\ time}{average\ customer\ demand}$$

THE ROLE OF TAKT IN CONSTRUCTION

DEVELOPMENT IN CONSTRUCTION

In the construction of buildings the first recorded use of Takt time for construction was during erection of the Empire State Building in New York in 1930. In this case location-dependent time plans were prepared in which multiple time-defined work steps were planned (Willis and Friedman, 1998). In the field of bridge construction from 1857 the Grandfey-Viaduct in Freiburg, Switzerland was produced using Takt. (Marti et al. 2001, 108)

Today Takt is also used in various construction processes. Examples include bridge construction (incremental launching method), underground construction (slotted walls using pilger rolling), tunnel construction (tunnel boring machines using lining segments) and excavation (digger-truck traffic coordination). What all of these construction methods have in common is that the product is completed repetitive. The use of a Takt is highly relevant in frequently repeated (nearly) identical procedures. As soon as the content of a Takt is planned, it can be continuously repeated. Hereby economies of scale can be used.

Conversely the approach of Takt is rarely used in the construction of buildings. Often not all levels of a building and the room layout are designed identically. These conditions make greater preparation and planning necessary in order to integrate the different areas into a common Takt. If the structure is more precisely considered, divided and detailed, repetitions become recognizable. In Germany there has been a noticeable increasing spread of the approach of takting the construction of buildings. Various projects currently using this method are known to the authors. For some years the approach has also been included in university teaching and research. In the IGLC community the term Takt was used and defined for the first time in 2005 in Bulhões et al. (2005, 100). Further articles from Frandson et al. (2013, 2014), Seppänen (2014) und Yassine et al. (2014) make use of the method. The approach to Takt planning of Frandson et al. (2013) states six steps to a takted production plan. Variations with associated buffer times are taken into consideration. The approach to control takted construction processes has so far not been considered so far.

Through using the Takt principle a construction project is divided into small time segments and spatial areas. The work in each area is determined and structured. The duration of the work packages for each trade can be better calculated or estimated using performance factors for each Takt area. If all trades agree upon these work packages with the goal of a nearly identical Takt effort (for example one week), a consistent production speed can be achieved (Friedrich 2013, 43). This leads to a stable construction process with less constraints. At the end of a Takt every trade must ideally have completed the required works.

TAKT PLANNING AND CONTROL IN CONSTRUCTION

INTRODUCTION

The opinion that construction projects are one-off projects, which are seldom repeated, is a widely held view in the construction industry. However if the composition of a building is viewed in greater detail, similarities can be recognized. For example a residential building living space is divided according to apartments, which generally have at least one bathroom. Through these identifiable repetitions, standardized processes on the construction site become beneficial. Takt and Takt planning aids in the implementation of these.

PROCESS ANALYSIS

In the process analysis, as a upstream step, the structure oft he project is divided in different work areas and the ideal trade sequence is defined. The steps of the process analysis are comparable to the first three steps of Frandson et al. (2013). This step is step is then further developed through including more participants. As soon as the team has a common vision for execution and the trade sequence, the input of the client is included. The customer determines milestones based on the division into functional clusters. Following this the project-pulled Takt planning can begin.

TAKT PLANNING

The Takt and Takt areas of a construction project are determined and these shape specific projects as a definite entity. This spatial entity/time slot must be filled using the content of the detailed value creation process determined during the process analysis.

The basis of the content is the sequence of works from the process analysis which divided the process into detailed working steps (see Work steps in Table 1). On the basis of these individual steps and the standard room unit (SSU), effort values can be determined and allocated (see method in Table 1). SSU is the smallest replicable space area. It should be noted, that all kind of adjusting has limits and dependencies. This means that for example a particular amount of manpower is required to complete a particular working step, or the size of a team results a minimum size of a Takt area.

Table 1: Leveling of the work packages

Work package	Work step	Perfor-mance factor	Mass of a SSU	Man-power	Duration for 1 SSU	Duration for a Takt area (3xSSU)	Total duration with a Takt of 5 days
A	1	0.5 h / m^2	25 m^2	2	6.25 h	18.75 h	4.785 h
	2	0.33 h /m	3 m	2	0.51 h	1.53 h	
	3	0.2 h / m	30 m	2	3.0 h	9.0 h	
B	4	1 h / pc.	1 pc.	1	0.5 h	1.5 h	
	5	2.5 h / m	12 m	1	2.5 h	7.5 h	
C	6	…	…	…	…	…	

Adding the time required for individual working steps to the time required (performance factors) for the work packages results in a sequence of works. This sequence must then be aligned to the project structure of Takt areas and Takts again. This is referred to as Takt Harmonization. The planned time cycle and floating buffer results in the required time for a Takt area. The time required for a work package must not exceed the duration of one Takt. The aim is for the best possible usage of the planned cycle. The most challenging part of the Takt planning is to derive a common production speed for the individual trades. The clear advantages of using this method are increased economic viability, better quality and timely completion. Takt planning is comparable to the three further steps of Frandson et al. (2013).

Takt planning is ideally prepared collaboratively by the entire project team. Through this use of a high level of specialist technical knowledge, execution of construction and process duration is greatly improved. The goal is for workloads to be as evenly matched as possible across the various trades and thereby to achieve a stable construction process. The Takt time can be calculated according to the following formula:

$$Takt\ time\ = \frac{Content\ Taktarea\ [entity\ =\ m2] * Effort\ Value\ [Time/Entity\ =\ h/m2]}{Selected\ Manpower}$$

The calculated takt time according to the perspective of the contractor must be compared with the demands of the client. If necessary, the Takt time can be adjusted through reduction of buffer times or through optimization and acceleration to adjust the demands of the customer.

As the work packages are rarely automatically suited to the planned duration of one Takt cycle, the harmonization operation shown in Figure 2 is carried out.

1. The time required can be increased or decreased by using more or less workers (see figure 2; No. 2: improving)
2. Work packages can be joined together to make up a single time slot (see figure 2; No. 3: levelling).

3. Working steps can be changed, optimized or replaced using products or processes

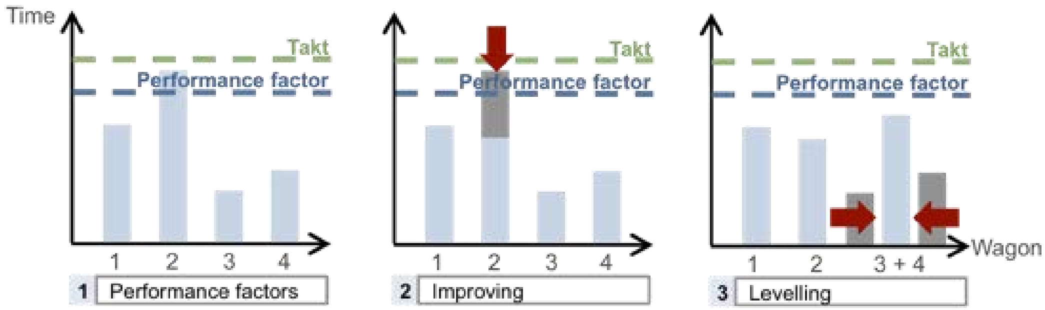

Figure 2: Ways of levelling the work packages (Lean Production Expert 2012)

In addition to the use of floating buffers, also calculation of fixed buffers at the end of every Takt is possible (e.g. weekend as buffer). The selection and use of buffers is essential for an efficient output.

After all work packages are divided into a Takt/time cycle, the individual slots are closed. This creates a continuous connection. This connection within a Takt is referred to as a 'wagon' or 'container'. If a wagon is made up of one or more work packages, it is to be defined. The sum of all wagons in a line, or sequence of works is defined as the so called 'work train'.

To prepare a production plan as can be seen in Figure 3, the work trains are carried over to the production plan according to their level of priority. The work trains cover the complete replicable sequence of value creation. Nonreplicable working areas must also be part of the production to ensure transparent production planning. These nonreplicable work areas include both time dependent and time independent work packages. The time independent work packages are in practice defined as 'workable tasks' Hamzeh et al. (2008, 641) and serve to balance the work packages.

According to the experience of the authors, the preparation of the production plan is a deciding factor. A classic Gantt chart should not be referred to in this case, as this form generally does not include spatial entities, or cannot be systematically incorporated. The authors recommend a diagram type including time and space be used where the place is defined in the form of a room, and therefore the value adding object is brought to the foreground (see Figure 3). From the customer's perspective the construction status of Takt area 1, and whether the task is being completed at the right time can immediately be recognized. This point is especially significant for project control.

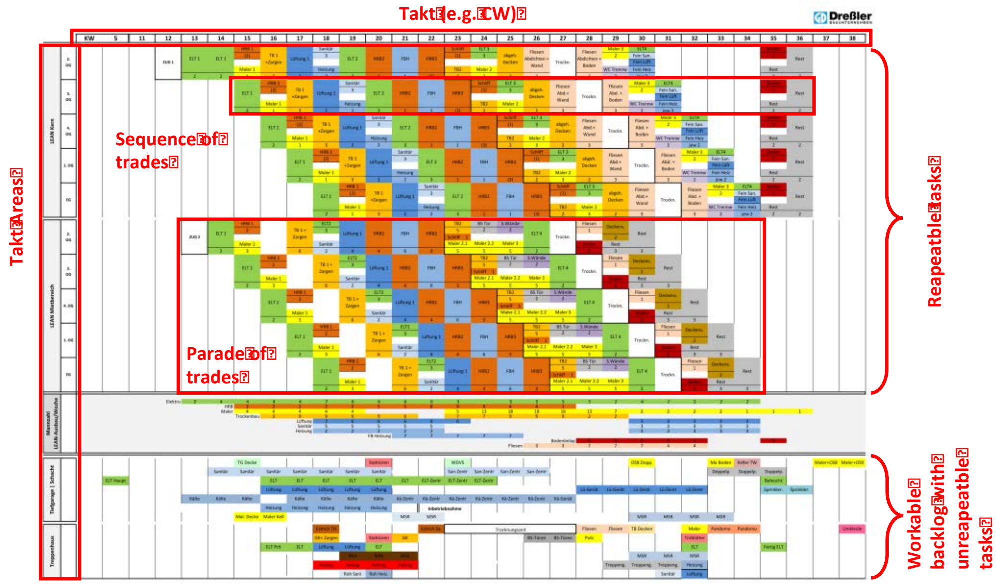

Figure 3: Preparation of a Takt plan of a general contractor

TAKT CONTROL

The use of Takt allows accurate and short-cycled control of individual works. Due to the short Takt times, the following Takt will be affected immediately, in case variations to the planned works occur. Potential disruptions are thereby visible at an early stage. The goal at the end of a Takt is, that all work is being carried out according the plan. A completed Takt plan is a not fixed concept. Rather it is an execution plan that is constantly evolving. Short-cycled adjustment of a Takt plan is important. This means for example if there is a disruption to a ‘station’ in the work train, an empty Takt (‘buffer wagons’) can be built in, individual work packages and wagons can be shifted to form a ‘catch up plan’. This can be considered an indicator of stability in comparison to PPC from the Last Planner System. Therefore reason short-cycled observations and control of the individual work packages is essential. Only through this the proportion of reactionary and costly control measures can be reduced. For the overall project this procedure leads to reduced risk due to the achieved stability of processes. Takt Control is responsible for maintaining the necessary stability. Systematic and short-cycled construction control is a significant success factor in the process of construction projects. However in construction practice this type of control is rarely used. All individual contractors are part of the management process to achieve a continual improvement process. In the stationary industries this is known as Shopfloor Management. In construction practice Takt meetings are held at the so-called construction control site office or the Takt Control Board. This board documents various information, figures and recommended actions. During daily Takt meetings, led by the site manager, the current working step displayed on the planning board is incorporated and adjusted. The foremen of the different trades participate in that meeting. Thereby this adjustment between the planned working step and the current status is completed for every Takt which allows for short-cycled implementation of the required measures (Kenley und Seppänen 2010, 44-54).

The required records and documentation should ideally be undertaken daily together with the subcontractors. Kenley und Seppänen (2010) further recommend that workers collect data on man hours spent between two takt meetings, and present these at each meeting.

This type of construction control also puts the location of value creation in focus and is also defined as Gemba. This is confirmed by a survey of 68 construction and project managers from mid-sized construction contractors questioned on the actual state of construction site management. When using a short-cycled control the employees of the contractors use an average of 46.6 per cent of their working hours for controlling of construction sites, whereas those following traditional processes used 27.8 per cent of their time for this. (Binninger et al. 2015)

CONCLUSION

When many people or production units are required to work directly with one another, coordination is necessary. As continuous comparison is rarely possible and 100 per cent uniform speed cannot be achieved in most systems, comparison must be undertaken at particular intervals. For this the use of a production Takt is a decisive factor. For every Takt beat the production must have reached the planned status so that the closely linked works can continue without disruption. Carried over to the field of construction, the required works of every trade must be completed in the allocated Takt beat. Within the Takt time, the trades are flexible and can divide the work content. The more short-cycled the Takt time is selected, the more effective the production system can be run. This effect was registered by the author's in their own projects. The deciding factor in keeping to a Takt is good planning and fine-grained management. A Takt plan is not a fixed concept, but rather should be changed according to the results of short-cycled meetings. The weekly work packages are determined on the basis of milestones which are agreed with the client during process analysis. The daily works are managed during the short-cycled meetings so that the work packages can be completed smoothly, and thereby the time schedule will be met. The use of Takt offers excellent possibilities to increase the stability of a production system and thereby improve long-term effectiveness.

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TOWARDS SHARED UNDERSTANDING ON COMMON GROUND, BOUNDARY OBJECTS AND OTHER RELATED CONCEPTS

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ABSTRACT

Since Aristotle, it has repeatedly been stressed that for engaging in meaningful discussion or debate, the discussion parties must share, besides a language, also knowledge, information, values and goals. What do we know today about this issue? How can that knowledge be used and advanced? The purpose of this paper is to consolidate our understanding on the many concepts that refer to preconditions for communication and collaboration in construction projects. The underlying research is conceptual by nature, and it is underpinned by a literature review. The findings show that currently there is a wide variety of terms and theoretical approaches that refer to the discussed phenomena. This situation invites for a conceptual synthesis and empirical research for its validation.

KEYWORDS

Shared understanding, boundary objects, common ground, mediating artefacts, standardized methods, situational awareness.

INTRODUCTION

Deservedly, "shared understanding" is one of the current buzzwords in construction, where it (or cognate terms) is used in connection with new forms of contracts like integrated project delivery (Aapaoja et al. 2013), as well as with building information modelling (Coates et al. 2010) and lean construction (Pasquire 2012). However, it

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emerges that different authors use this term in differing meanings, and also there are related terms with similar or at least overlapping meaning.

In view of this, this paper aims at adding conceptual and terminological clarity to the many concepts that refer to preconditions for communication and collaboration generally as well as in construction projects. It is structured as follows. After short presentations of six related concepts based on the literature, we briefly discuss them and draw conclusions for future work. The concepts discussed are: shared understanding, common ground, boundary object, mediating artefact, standardized method and situational awareness.

TERMS AND CONCEPTS

SHARED UNDERSTANDING

In a first comprehensive study on team work and social interactions in design, Cross and Cross (1996) identified that design teams spend a lot of effort to coordinate individual process of information processing in order to reach shared understanding of the problem. According to these authors, the teams have to manage conflicts based on different interpretations of ideas, concepts and representations. Shared understanding implies an overlap of understanding among design participants in the task (Maher et al. 1996), and a lack of shared understanding causes unnecessary iterative loops (Valkenburg & Dorst 1998) that can be further correlated to the notion of waste on design. Moreover, without shared understanding, decision-making processes will not be supported by all members (Valkenburg, 1998). In this case, later activities in the design process can be hampered by different views of the team members on fundamental topics (Valkenburg 1998). Arias et al. (2000) have also indicated the importance to focus at the social aspect of creating shared understanding in collaborative environments through human-computer interactions.

More recently, in product design research Kleinsmann (2006) defined shared understanding as a similarity between individual perceptions on the conceptual content of design. A more comprehensive definition is proposed by Smart et al. (2009), defining shared understanding as “the ability of multiple agents to exploit common bodies of causal knowledge for the purpose of accomplishing common (shared) goals”. These authors also describe shared understanding “as the ability of multiple agents to coordinate their behaviours with respect to each other in order to support the realization of common goals or objectives.” Seeing understanding as an ability, or “meaning in use”, gives strength to the viewpoint that understanding is more than knowledge; it is reasoned action and has a dynamic state (Bittner & Leimeister 2013).

In spite of its development in the context of military coalitions and further applications on Systems Science, the definitions of shared understanding presented in Smart et al. (2009) can be related to the context of complex project delivery in construction. This means that collaborative multidisciplinary design process involves knowledge (understanding) creation and sharing to be integrated through design communication (Kleinsmann & Valkenburg 2008). In this case, representations can be correlated with process of developing mental models, which are mechanisms that humans use to generate descriptions and formulate predictions on how systems works, and they play an important role in enabling understanding (Smart et al. 2009). This ability to engage in different aspects of the problem that are nevertheless collectively coordinated to each other is an indicative of shared understanding in collaborative situations (Smart et al. 2009).

This discussion on shared understanding embraces the dynamics of social interplay related to collaborative design, and it has been constructed on top of sociological and psychological research based on the concept of understanding, however with no further underlying theory of shared understanding. This implies that there is a lack of knowledge concerning the specific patterns of building shared understanding in collaborative design (Van den Bossche 2011).

COMMON GROUND

Common ground is a concept deriving from classical rhetoric. Already Aristotle (1998) contended that “if any two people are going to have a debate, there needs to be some common ground”. However, the term common ground is of Anglo-Saxon origin. Common ground was a legal term, equivalent to “common land” or “commons”, which was used in a metaphorical sense already in the 17th century (Koskela 2015).

Indeed, 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 (Perelman & Olbrechts-Tyteca 1969).

The idea and term of common ground were transmitted in the rhetorical tradition to the modern time. A turning point happened at the end of the 1970s, when several scholars, including Stalnaker (1975), Clarke and Wilkes-Gibbs (1986) and others, rediscovered the idea and started to research it.

For Clark (1996), common ground between speakers is "knowledge, beliefs, and suppositions they believe they share". The idea that common ground is a dynamic construct that is mutually constructed by interlocutors throughout the communicative process (Kecskes & Zhang 2009) is commonly accepted. In this regard, Clark and Brennan (1991) introduce the term grounding: in communication, common ground cannot be properly updated without a process they call grounding. The authors further contend that grounding depends on the purpose and medium of communication. By way of illustration, one interesting technique of grounding is referring to objects and their identities. This can be done through, say, indicative gestures, for example pinpointing.

Klein et al. (2005) extend the discussion to joint activity in the context of team coordination. To them, key aspects of common ground include: 1) The types of knowledge, beliefs and assumptions that are important for joint activity, including knowledge of roles and functions, standard routines, and so forth; 2) Mechanisms for carrying out the grounding process: to prepare, monitor and sustain common ground as well as to catch and repair breakdowns; 3) Commitment of the parties in a joint activity to continually inspect and adjust common ground. The mentioned authors have further studied the loss of common ground, and list a number of mechanisms leading to that. One reason, confusion on who knows what, is found so frequently that is has been named as Fundamental Common Ground Breakdown (Klein et al. 2005).

The relation of visual information and common ground has recently started to be studied (Kraut et al. 2002). Research shows that visual information supports conversational grounding (Gergle et al. 2013).

Empirical, theory testing research on common ground is somewhat scarce. Beers et al. (2006) found that paying attention to the negotiation of common ground by having participants verify their understanding and having them explicate their positions could increase the effectiveness of group decision support systems. The notion of common ground occurs also in prescriptive literature; for example Gray (1989) has developed a methodology based on common ground, for organizational problem solving, conflict resolution, mediation, and negotiation.

BOUNDARY OBJECTS

The concept of boundary objects (BO) was introduced in 1989 by Star and Griesemer to describe objects used by different actors for individual or collaborative interdisciplinary work, despite the absence of consensus. The term boundary describes a "shared space, where exactly that sense of here and there are confounded" (Star 2010), or a space where two or more worlds are "relevant to one another in a particular way" (Akkerman & Bakker 2011). Thus, boundary objects are used to describe objects that "inhabit several intersecting social worlds and satisfy the informational requirements of each of them" (Star & Griesemer 1989).

However, the meaning of boundary objects has been changing along the years. Lee (2007) defines boundary objects as a useful "theoretical construct with which to understand the coordinative role of artefacts in practice". In spite of the different definitions, boundary objects have some common aspects: (a) may be an abstract or concrete object; (b) must be "plastic enough to adapt to local needs"; (c) "robust enough to maintain a common identity across sites" (Star & Griesemer 1989); (d) must be temporal; (e) based in action, it means, its materiality derives from actor's action; and, (f) subject to reflection, or interpretive flexibility (Star 2010).

Furthermore, Star (2010) highlights other aspects that turn an artefact into a boundary object: material/organizational structure, and scale/scope. Normally, BO arises in organic infrastructures according to "information and work requirements perceived by groups who wish to cooperate" (Star 2010). Moreover, the level of scale and scope make an object more useful or not, for example, the use of BO at the organization level (Star 2010); otherwise any object might become a boundary object.

The concept of boundary object has been applied in different research areas, e.g., collaborative information systems, organization science, and information science (Lee 2007) to refer to a mediation role to improve the collaboration and common understanding among different social worlds. Boundary objects can develop a (1) syntactic role, when the object needs to develop a common lexicon for transferring the knowledge among parties; (2) semantic role, when it's necessary to create common meanings to identify differences and dependencies and translating the knowledge; and (3) pragmatic role, when the object establishes common interests for making trade-offs and transforming knowledge (Carlile 2004).

In research on construction, boundary objects have been understood as transferring and translation devices to improve the collaboration between designers and contractors. Such artefacts include: timelines, prototypes, sketches, designs and 3D CAD models.

Forgues et al. (2009) point out that the implementation of complex technologies, such as BIM, could act as a transformational device within the construction of new knowledge by experimentation. However, they also state that pragmatic barriers cannot be overcome without proper governance. All in all, boundary objects can facilitate the knowledge sharing in an integrated design process, but not resolve problems related to the pragmatic barriers by themselves (Forgues et al. 2009).

MEDIATING ARTEFACT

Mediating artefact is a concept with roots in the Soviet activity theory pioneered by Lev Vygotsky and Alexei Leont'ev (Bedny and Meister 2014) and later expanded by Engeström (2000) into Cultural-Historical Activity Theory (CHAT). The descriptive Activity Theory begins with the notion of activity as a system of human 'doing'; i.e. object-oriented, collective and culturally mediated working, or activity system, to transform the object into a desired outcome through the use of mediating artefacts (Engeström 2008).

Mediating artefacts, including tools, procedures, processes and accepted practices are expressions of cognitive norms and expected standards, or in other words standardized and externalized (objectified) cognitive procedures and structures, representing distributed cognition (Macpherson et al. 2006). These are 'artefacts of knowing' through and against which different communities can represent, interpret and contribute to the understanding of ongoing and unfolding activities (Ewenstein & Whyte 2005). 'Mediating artefacts' provide a syntax for intersecting work of knowledge domains, allowing the exploration of semantic differences and helping the joint transformation of knowledge between practices (Carlile 2004). Consequently, 'mediating artefacts' are central to both the representation of past learning and the construction of new meanings (Carlile 2004).

Mediating artefacts are broadly defined as usage of 'instruments, signs, language, and machines' (Nardi 1996), which according to Carlile (2004) have different capacities to represent common knowledge. Mediating artefacts help practitioners to make informed decisions and choices in order to undertake specific activities and they differ in a number of respects (Conole 2009): their format of presentation (textual, visual, auditory, or multimedia); their degree of contextualization (from abstract to contextualized); the level of granularity (i.e., the amount of details available within the mediating artefact about the activity); the degree of structure (flat vocabularies vs. typologies).

Cole and Engeström (1993) distinguished between artefacts and tools, where artefacts have diverse meanings, and tools are a subcategory of this wider overarching concept of artefacts. Based on the different processes artefacts represent, Engeström (1999) conceptualized different types of artefacts: 'What' artefacts, used to identify and describe objects; 'How' artefacts, used to guide and direct processes and procedures on, within or between objects; 'Why' artefacts, used to diagnose and explain the properties of objects; 'Where to' artefacts used to envision the future or potential development of objects.

Engeström et al. (1999, 382) explain the construction of artefacts as follows: "The artefact-mediated construction of objects does not happen in a solitary manner or in harmonious unison. It is a collaborative and dialogical process in which different perspectives and voices meet, collide and merge. The different perspectives are rooted in different communities and practices that continue to co-exist within one and the same collective activity system."

STANDARDISED METHODS

Star and Griesemer (1989) proposed two major factors that contributed to the successful co-operation between biologists and amateur naturalists: boundary objects and methods standardisation. In that article, methods standardisation was introduced first and most importantly was claimed to establish a '*lingua franca*' to enable co-operation between amateurs and professionals (Star & Griesemer 1989). However, it was the less stressed concept, and the title of article only referred to boundary objects but not to methods standardisation (Lee 2007).

The concept of standardisation is important to the concept of boundary objects in the way that boundary objects are heavily dependent on the concept of standardisation (Lee 2007). On the other hand, this method is not sufficient to ensure co-operation as such across divergent social worlds, and boundary objects are necessary (Star & Griesemer 1989). Star (2010) later concludes that standards and boundary objects are as inextricably related.

Standardised methods accentuate the collaboration of actors to **'get work done'** and simultaneously to maintain the integrity in their respective social world. Standardised method emphasises on **how** and not what or why; it makes information compatible and allows for a longer 'reach' across the wider divergent world (Star & Griesemer 1989).

Fujimura (1992) contends that the concept of boundary object is too flexible. Due to this limitation of boundary object, Fujimura (1992) conceptualised "standardised package" which is less abstract, less ambiguous and more structured. The standardised package, which is a combination of multiple boundary objects with the standardised tools, serves as interfaces between multiple social worlds, and facilitates the flow of resources (e.g. concepts, skills, materials, techniques, instruments) among multiple lines of work (Fujimura 1992). These are conventionalised ways of carrying out tasks or in other words, standard operating procedures, which could be easily adopted and incorporated by people in different lines of work to develop a common practice (Fujimura 1992).

However, the proposed packages have not been validated by other researches and there is still a gap in knowledge on how actors from different social worlds can collaborate while there are no pre-existing standards (Lee 2007). This gap is visible, for instance, in the context of Information systems (IS), as the number of IS and computing devices within organisations is exponentially growing, and there is a need to standardise and integrate them to enable dissimilar systems to co-operate and interoperate (Nyella & Kimaro 2015).

Situational awareness

Adamu et al. (2015) contend that an effective team task depends on a shared situational awareness among team members. Generally, situational awareness is considered as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (Endsley 1995, 36). However, a definition more suitable to design was proposed in the study of team cognition by Durso, Rawson and Girotto (2007 cited in Wickens 2008, 164) as the "comprehension or understanding of a dynamic environment". This is particularly important in the context of collaborative design, in which the issue of team situation awareness emerged as important factor in understanding team dynamics. In the research of teamwork behaviour, Endsley and Jones (2001) argue that it deals with what each worker knows about the understanding and workload of the co-worker, and how this is supported by communication between them. In reconfiguring Endsley (1995) definition, situation awareness would be the capacity to perceive and comprehend the characteristics of an environment within time and space supporting the realization of predicted futures aligned with a task or project.

DISCUSSION

The preceding reviews show that a number of connected ideas on what happens when people do something together, be it communication or action, are emerging from many different traditions and applied in many contexts. This multitude of approaches is an opportunity to create a rich synthesis; also it will be possible to identify gaps to guide future research. Unfortunately, this situation is also prone to create confusion and misunderstanding.

In spite of the many various terms used, it is possible to see invariantly surfacing ideas in different approaches. The dynamic nature of the common ground between parties is one such idea. Also, the taxonomies of the different aspects or parts of the common ground show considerable similarity.

It is tempting to contrast the reviewed approaches against the classical communication theory, which assumes that communication is about transferring information from one point to another. The reviewed approaches may show that the classical communication theory has had a too narrow and simplistic view on its subject – indeed they provide a serious critical challenge to it. Interestingly, this classical communication theory has been the background theory to the majority of information systems and managerial research.

This situation invites for fundamental research on communication and collaboration, for further progress and consolidation of our understanding. On the other hand, it seems that the opportunities for practical implementation of this understanding are huge. Indeed, many recently found methods for collaboration, say the methods of Big Room, A3 and Choosing by Advantages, easily allow theoretical explanation through the ideas discussed, as initially argued in (Koskela 2015).

CONCLUSIONS

As a phenomenon, collective human action is ubiquitous, and of extreme importance for the mankind. In view of this, theorizing on collective action has developed slowly and has remained fragmented. However, a review of existing approaches reveals a multitude of fertile ideas and wide agreement on many common concepts, in spite of differing starting points.

Management practices, both generally and specifically in construction, have in the recent years developed towards the target of supporting, enabling and realizing collaboration. These efforts have been practically based, without any theoretical backing. Now, it seems that the theoretical resources discussed above can with benefit be used for analysing, explaining and improving such efforts towards collaborative working. However, a synthesis of the many concepts and approaches, as well as added terminological clarity is needed. In turn, practical collaboration efforts also invite theory-testing research for validating and consolidating this important field of theory.

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QUICKER REACTION, LOWER VARIABILITY: THE EFFECT OF TRANSIENT TIME IN FLOW VARIABILITY OF PROJECT-DRIVEN PRODUCTION

Ricardo Antunes[1], Vicente González[2], and Kenneth Walsh[3]

ABSTRACT

Based on the knowledge of dynamic systems, the shorter the transient response, or the faster a system reaches the steady-state after the introduction of the change, the smaller will be the output variability. In lean manufacturing, the principle of reducing set-up times has the same purpose: reduce the transient time and improve production flow. Analogously, the analysis of the transient response of project-driven systems may provide crucial information about how fast these systems react to a change and how that change affects their production output. Although some studies have investigated flow variability in projects, few have looked at variability from the perspective that the transient state represents the changeovers on project-driven production systems and how the transient state affects the process' flow variability. The purpose of this study is to investigate the effect of changes in project-driven production systems from a conceptual point of view, furthermore, measuring and correlating the transient response of five cases to their flow variability. Results showed a proportional relationship between the percentile transient time and flow variability of a process. That means that the quicker the production system reacts to change; the less the distress in the production output, consequently, lower levels of flow variability. As practical implications, lean practices focusing on reducing set-up times (transient time) can have their effects measured on project-driven production flow.

KEYWORDS

Flow, variability, production, Single Minute Exchange of Dies (SMED), productivity function

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INTRODUCTION

The importance of the time spent in production changeovers has been well-known for a long time (Taylor, 1911), as much as structured approaches to reduce such time (Gilbreth, 1911). However, it was later with the development of 'Just-In-Time' that progress was made to lessen the changeover time. Observations of how to reduce the time spent on the exchange of dies on automotive pressing machines resulted in a structured methodology capable of bringing down the time spent in changeovers from hours to minutes (Shingō 1985). Widely applied in the manufacturing till this day, the Single Minute Exchange of Dies (SMED) consists of seven basic steps. The steps are:

(I) observe and measure the current methodology;

(II) separate external of internal activities;

(III) transform internal activities into external ones;

(IV) simplify remaining internal activities;

(V) make the external activities more efficient;

(VI) standardize the new procedure; and

(VII) repeat the method for further improvement

THE 3 UPS OF CHANGEOVER

A process changeover (Figure 1) consists of three 'ups':

Cleanup

Cleanup is the removal of previous product, materials, components, and/or residuals from the production line or site. It may range from minor tasks such as cleaning after a painting job has finished to major work such as a tower crane disassembling. '5S' practices perform a significant role in the cleanup stage, simply because if there is less to clean, it can be done faster (Womack, Jones, and Roos, 1991). Hence, keep a clean and organized site supports a quicker cleaning. Ideally, the cleanup finishes with the production output. It means that once a production output reaches zero, the site is clean. Accordingly, the cleanup stage can be measurable. It starts when the input of the production system ceases. In the best case scenario, the cleanup finishes when the process output reaches zero, *i.e.*, there is nothing else to be produced or cleaned. Otherwise, the cleanup finishes when everything needed in the process is removed.

Setup

Setup is the group of activities of converting the site to run a new process. The conversion requires adjusting or parametrizing equipment to match the requirements of the next production process or by replacing non-adjustable equipment. Usually, it involves a combination of both. For that reason, the resources are applied for preparing the site for the process while the production process stands still waiting to start. This situation is the *muda* of waiting (Ohno, 1988), or simply waste. The setup stage is utterly unproductive; it adds no value. Therefore, lean practices aim to 'zero setups' or 'eliminate setup'. The setup is also measurable. It begins when cleanup finishes and ends at the production kick-off.

Startup

Startup (transient) is the time immediately after a process kick-off until the full process operation (steady-state). The initial moments involve 'learning' and fine-tuning the equipment and the pace of work. In this stage, jams and stoppages are frequent causing defective products and variations in the production output (Shingō 1985). The production system often underperforms at the setup stage in comparison to the production at steady-state.

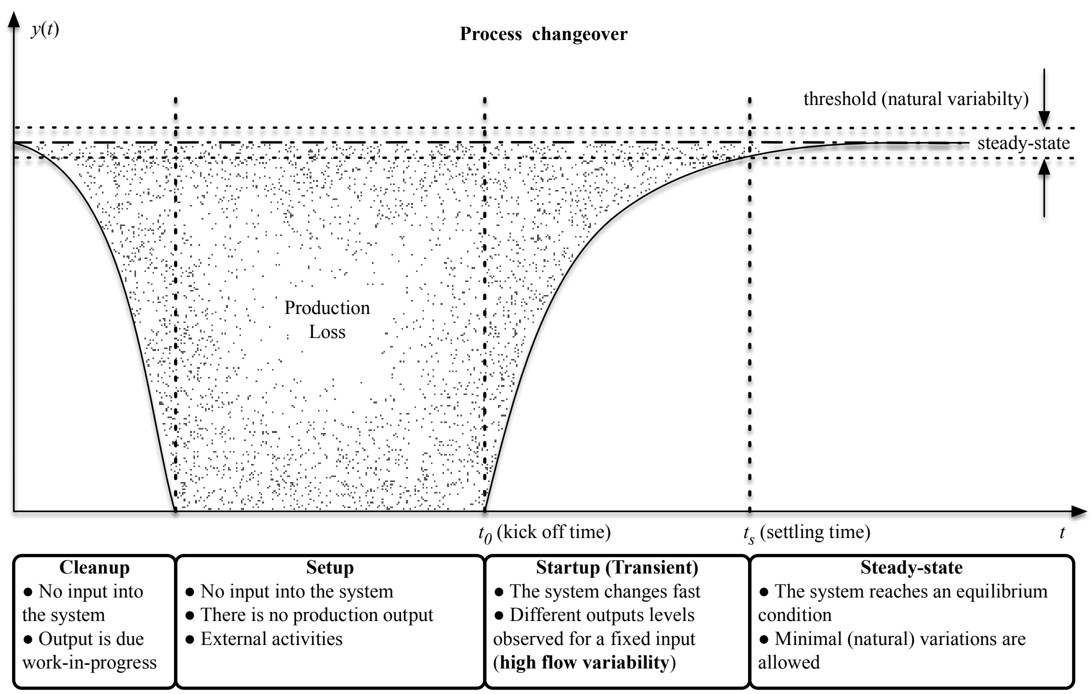

Figure 1 - Process changeover

SMED AND CONSTRUCTION

The main focus of SMED is the transformation of internal activities of the setup stage to external activities. In manufacturing, an internal activity is any operation that can only be performed if the machine is shut down (for instance, attaching or removing the dies). An external activity can be executed when the machine is running (Cakmakci, 2008). In project management terms, internal activities are in the critical path, while external activities are parallel to the critical path. Hence, in a project-driven process, the application of SMED means removing activities that are not hardwired to the critical path and executing them in parallel, furthermore, resulting in a compressed critical path. In the end, SMED practices in project management can be seen as a method for fast tracking the project schedule.

The concept and benefits of SMED are well known in the construction industry, especially within the lean construction community. An example of the use of SMED practices in construction is the offsite fabrication (Gibb, 1999). On offsite fabrication building tasks are performed externally to the site and what is left is a reduced number of assembling activities to be performed onsite. Automation is another example of the use of SMED, in particular, the application of techniques to eliminate adjustments and improve mechanization. Construction processes are flexible, constituted by a workforce, machinery and equipment with relatively general purpose (Hayes and Wheelwright, 1979, p. 134). Such flexibility favors the adaptation of existing resources to new processes over resources replacement in the setup stage. However, there is still the 'adjusting or parametrizing equipment' to do. Automatic parametric machinery may reduce the time of setup times by performing the conversion faster and improve startup because it may reduce the possibility of human error while adjusting the machinery. Although the use of offsite fabrication and automation in construction are strongly related to SMED and widely present in the construction industry, little is the discussion about the structured application of SMED as performed in manufacturing. Even though, the implementation of SMED in construction is likely to be easier than in manufacturing based on general purpose equipment and workforce in the construction industry.

As all continuous improvement techniques, SMED requires measurement, control, comparison and benchmarking. As measurements, SMED usually utilizes the estimator of Process Performance Index (assuming that the process output is approximately normally distributed), C_{pk}, and Process Performance, P_p, values for judging a process, whether it is capable of improvement or not (Cakmakci, 2008). C_{pk} is the result of the upper specification limit minus the mean of the output divided by three times the output sample standard deviation; or, the mean of the output minus the lower specification limit divided by three times the output sample standard deviation. Whatever shows the minimum value (Montgomery, 2009, p. 355). The P_p is given by the difference of upper specification limit and lower specification limit (here plus and minus two percent around the mean, matching the threshold limits) divided by six times the standard deviation of output sample (Montgomery, 2009, p. 363).

Those formulas provide unique values of C_{pk} and P_p that can be used in the judgment, what works fine for manufacturing. Construction is a different story. The difficulty in judging a construction process is due to the short run (batch size) of its production (Antunes and Gonzalez, 2015). In other words, there is not a long enough—sometimes any—steady-state to produce useful data (normal distribution around the steady-state value) to use C_{pk} and P_p. The highly variable and long transient state of project-driven processes disrupt the accuracy of the values given by C_{pk} and P_p. Because they end up accounting for variations in transient—and consequently setup—stages rather than the variations at steady-state. Another difficulty is in defining what are the upper and lower limits of variation once project management problems may have several suitable solutions.

FLOW VARIABILITY

In a process chain (Figure 2), the output of a process is the input of another, consequently, establishing a flow. When variations of the output of the process i affects the input, and/or behavior of the following process, i+1, this is called flow variability.

How much the output variation of the process i affects the process i+1, depends on two factors. One is the coefficient of variation of the arrival rate of the process i+i, c_a. In a process chain, without yield less or rework, the arrival rate of the process i+1 is equal to of the departure rate of the process i, as well as the coefficient of variations, $c_{d(i)} = c_{a(i+1)}$. That is known as the conservation of material (Hopp and Spearman, 2001, p. 253).

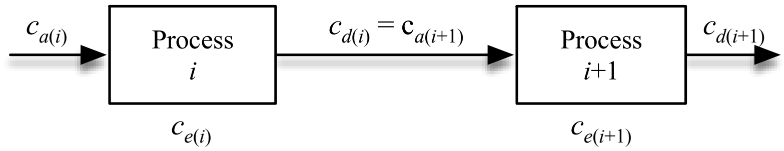

Figure 2: Propagation of variability between processes. Adapted from Factory Physics: Foundations of Manufacturing Management, 2nd ed. (p. 262), by Hopp, W. J., and Spearman, M. L., 2001, Irwin McGraw-Hill.

The second factor is the utilization, *u,* of the process i+1. u values close to one indicate a process almost always busy, on the other hand, values close to zero points out a process nearly always idle. Since u is likely to assume values between zero and one the output variation of the process, $c_{d(i+1)}$, is given by Equation 1. Accordingly, if the output of the upstream process i is highly variable, the output of the downstream process i+1 is also highly variable (Hopp and Spearman, 2001, p. 261).

$$c^2_{d(i+1)} = u^2 c^2_{e(i+1)} + (1 - u^2) c^2_{a(1+i)}$$

Equation 1: Coefficient of the departure of the downstream process

MEASURING PROCESS' TRANSIENT

The direct method of measuring a process' transient is to compute the amount of output at regular intervals of time, *e.g.*, 'Time and Motion' (Taylor, 1911). Nevertheless, to calculate the transient time, t_s, the process must reach the steady-state. Hence, the data collection must proceed until the steady-state is reached and is undisputed that the process is in this state. Such procedure seems impractical as a non-automated task. Because, that means to utilize a workforce to monitor, measure and count the production output regularly in short periods of time. Even, after all, it may be impossible obtaining the process' transient time because construction processes often do not reach the steady-state.

PRODUCTIVITY FUNCTION METHOD

A productivity function, $P(t)$, represents the relation between the output function, $Y(t)$, and the input function, $U(t)$, of a project-driven production process, $Y(t) = P(t)*U(t)$, * symbolizes the convolution operator. Approaching the production process as a dynamic system the productivity function accounts for the transient and steady/unsteady-state (Antunes, González, and Walsh, 2015). The transient time is given by the transient analysis (Figure 2) of a processes' productivity function. The transient time, t_s, is the time the output takes to reach the steady-state value, or a threshold around the steady-state value (usually, –+2%) from the moment a unitary step input is applied, t_0. The step input acts as an off-on switch, *e.g.*, a light switch, which the input changes instantaneously from zero to one. The change in the input provokes the reaction of the system that tries to adapt as fast as possible (the bulb light filament warms once there is an electric current). Later on, the output tends to a constant value when $t \rightarrow \infty$ (the filament reached a temperature in which it produces a steady amount of light). The percentile reaction time is obtained by dividing the process transient time, t_s, by the total process time, t_t.

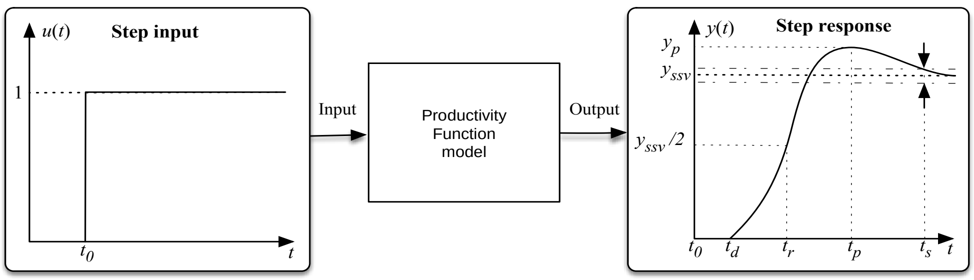

Figure 2 - Transient analysis

Some studies have investigated flow variability in projects. However, few have investigated the relation and effects of the transient state on flow variability of project-driven production systems. This study aims to examine, from a conceptual standpoint, the effect that changes in project-driven production systems have on their flow variability. Furthermore, measure and correlate the transient response of five cases to their flow variability.

METHOD

This research analyzed five cases with different sample sizes, and the processes compile various activities in construction. The cases are:

Case 1: drilling an offshore oil well (Antunes et al., 2015),

Case 2: wall assembling (Abdel-Razek, Elshakour, and Abdel-Hamid, 2007),

Case 3: setting formwork for slabs,

Case 4: group of activities (foundation excavation and backfill) from a housing project, and

Case 5: wall plastering (González, Alarcón, Maturana, Mundaca, and Bustamante, 2010).

The commonality among the cases is that they configure a system, *i.e.*, they are constituted by input, transformation process, and output.

First, the process output variation is measured. Process Performance Index, C_{pk}, and Process Performance, P_p, are obtained for the cases and shown in Table 1. A third measurement of output variation is given by the coefficient of variation (Hopp and Spearman, 2001, p. 252) of the departure times the process i, $c_{d(i)}$. That is the result of the ratio of standard deviation of the time between departures (standard deviation of the output) and the mean departure rate (output mean). The results are also shown in Table 1.

Before a productivity function can be obtained, an accuracy benchmark must be set. Thus, a first-degree polynomial model (FDP), $y(t) = \alpha u(t)$, is estimated using the regression analysis and the goodness of fit sets the benchmark. The productivity functions are then estimated by trial and error approach (Antunes et al., 2015). Later, the transient time, t_s, is obtained in the transient analysis (Figure 2) and the percentile reaction time can be determined.

RESULTS

Table 1 displays the transient analysis results given by the production function and the flow variability obtained by statistical means. Rather than sorted by case number, Table 1 was sorted by ascending 'percentile reaction time' to ease visualization and correlation between the two methods. Table 1 shows that as the percentile reaction time values increase the values of C_{pk} and P_p decrease, indicating a lower estimated probability of a process' output being within the limits. Additionally, Table 1 shows as the percentile reaction time values increase the coefficient of variation of the processes also increase meaning that the output variation increases. Consequently, the flow variability (Equation 1) also increases.

It is important to mention that the result of Case 2 has the highest percentile reaction time of the cases. The percentile reaction time is over 100% indicating that even if the processes input was kept constant during the process life spam the output would not reach the steady-state, or that process production run is too short for reaching the steady-state. Hence, it can be said that the process described in Case 2 is unsteady. The second point on Case 2 is that it is the only one with 'moderate variability' ($0.75 < c_d < 1.33$). Actual process times are usually 'low variability', $c_d < 0.75$. For a system with workload evenly distributed among the resources, it means that the process operates around the practical worst case (Hopp and Spearman, 2001, p. 232) with characteristics of processes with short adjustments (Hopp and Spearman, 2001, p. 254).

Table 1 - Flow variability and percentile reaction time

Case	Transient (settling) time t_s	Total process time t_t	Percentile reaction time t_s / t_t	*Process capability index* C_{pk}	*Process performance* P_p	Std. dev. departures σ_d	Departure rate r_d	Coefficient of variation $c_d = \sigma_d / r_d$
1	4.67	184	2.54%	0.2438	0.5354	95.22	3481.40	0.0273
4	13.11	210	6.24%	0.0144	0.0344	14.89	32.12	0.4634
5	1.23	18	6.86%	0.0110	0.0260	278.44	458.68	0.6070
3	1.82	8	22.71%	0.0108	0.0258	315.13	510.27	0.6176
2	55.85	20	**279.26%**	0.0085	0.0204	27.81	35.55	**0.7824**

t_s – transient (settling) time
t_p – total process time
r_d – departure rate (output mean the output, *i.e.*, $\bar{y}$)
σ_d – standard deviation of the time between departures (standard deviation of the output, i.e., σ_y)
c_d – coefficient of variation of the departure times ($c_{d,} = \sigma_d / r_d$, *i.e.*, CV = $\sigma_y / \bar{y}$)
C_{pk} – process capability index
P_p – process performance

Figure 3 shows the step response of production functions shown in Table 2, Cases 1, 4, 5, 3, and 2.

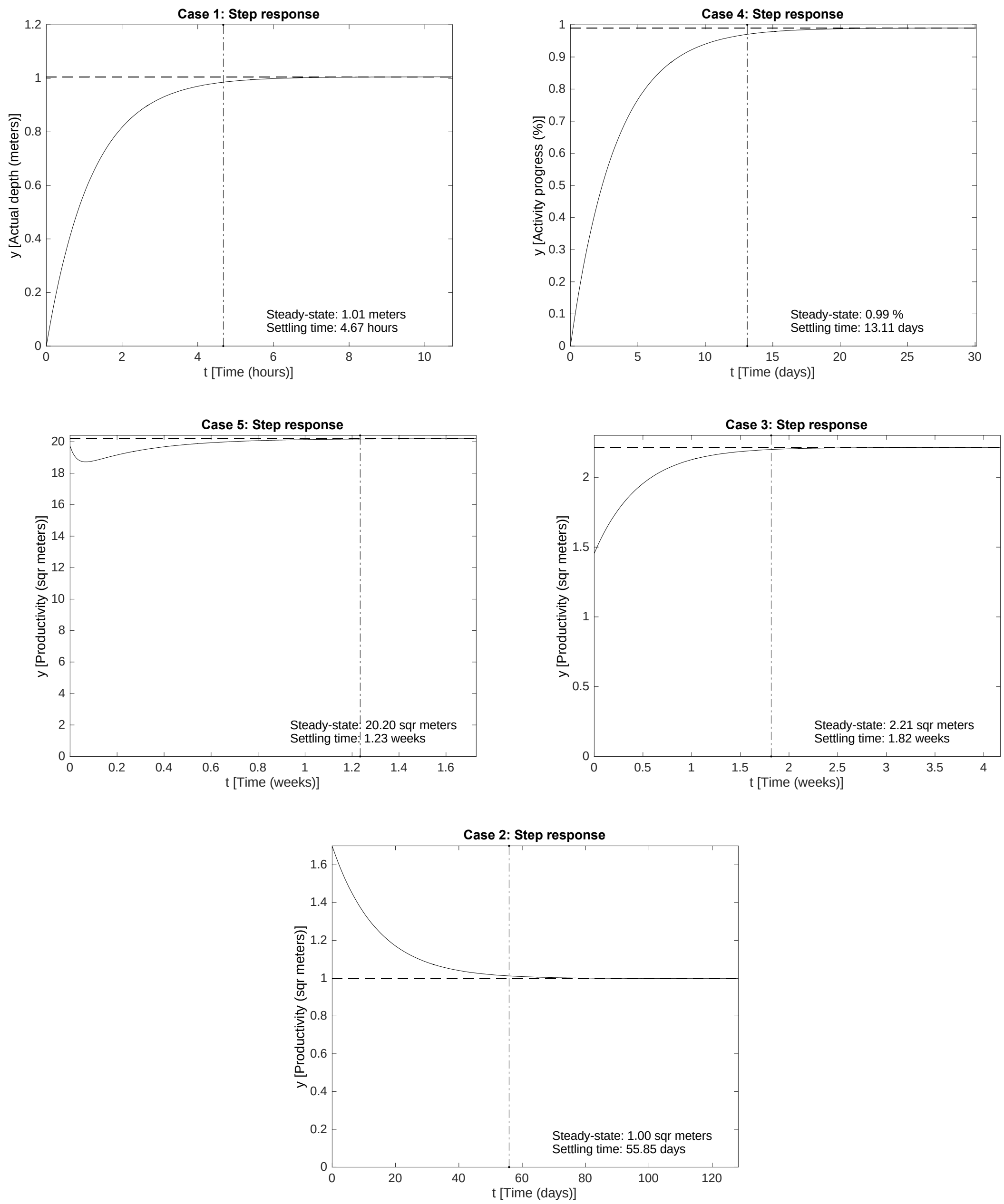

Figure 3 - Transient analysis of Case 1, Case 4, Case 5, Case 3, and Case 2

Table 2 shows the production functions, in the time domain, obtained in for the cases and used in the transient analysis, sorted in the same order as Table 1.

Table 2 - Productivity Functions

Case	Productivity Function
1	$P_1(t) = 0.8417\,e^{-0.8369t}$
4	$P_4(t) = 0.2955\,e^{-0.2984t}$
5	$P_5(t) = 7.142275814\,e^{-3.444656802t} + 19.74\,\delta(t) - 54.39107581\,e^{-33.6753432t}$
3	$P_3(t) = 1.455\,\delta(t) + 1.635385\,e^{-2.153t}$
2	$P_2(t) = 1.699\,\delta(t) - 0.04910796\,e^{-0.07004t}$

CONCLUSION

Results show a proportional relationship between the percentile transient time and flow variability of a process, confirmed by the coefficient of variation and process capability index calculations. These findings thus lend support that the quicker the production system reacts to change; the less is the distress in the production output, consequently, lower levels of flow variability. The findings align with what is known about dynamic systems and operations management. In manufacturing, the larger the batch, the more efficient the production process becomes. A larger batch requires a longer run time, hence the more irrelevant the setup time becomes when compared to the total run time. The same behavior was observed in construction when calculated the processes' Percentile reaction time using productivity functions. However, in project-driven processes increase the batch size and run times are not desired. Increased batch sizes imply producing more than what is needed: scope creep. That is the *muda* of over-production. Prolonged run times translates into extended activities duration. If the scope is constant the work should be done at a slower peace: decrease of productivity. Hence, the likely option is to reduce the time spent on the startup (transient time). In this fashion, productivity functions may provide a way to measure, visualize and compare the transient state of project-driven processes. Reliance on this method must be tempered, however, because the number of cases analyzed was small. Therefore, it would be beneficial to replicate this method in additional cases of project-driven systems in construction. As practical implications, the understanding of the effects of the transient state on the process variability may induce practitioners to re-evaluate the application of some Lean practices in construction. For instance, SMED practices that focus on reducing set-up times (transient time) can have their effects measured on project-driven production flow supporting a quantitative and structured application of this method.

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DESIGN AND ENGINEERING – MATERIAL ORDER

Lars Andersen[1]

ABSTRACT

The problem to be addressed in this paper is: why does the development of creativity based on interaction and dialogue between equal individuals stand opposed to an effective decision-making system that promotes process control and reduces design errors in the design process? The purpose of the research is to improve the new forms of design and engineering processes. The research method is a combination of formative process research, process tracking, and phenomenological analysis. The research case is the construction of a hospital. Construction in the oil industry (offshore) and shipbuilding are supporting cases. The empirical study confirms that reciprocal dialogue and the spirit of the partners' independence and equality contribute to increased creativity in the design process, but that there is still great potential for further development. The study also reveals that it is problematic to combine a strong dialogue orientation and collaboration in the design process with an efficient decision-making system. A proposition in this paper is that a satisfactory illumination of the problem to be addressed requires an extension of the existing lean discourse: The paper first discusses language action theory and the eighth flow approach in an extended theoretical and epistemological context. It then expands the discourse using modern organizational system theory and a material-technological approach.

KEYWORDS

Design, complexity, collaboration, communication, materiality

INTRODUCTION

The traditional design process is sequential-linear (Bølviken et al. 2010) with a corresponding decision-making system: The architects first make their drawings and decision premises for the Structural Consultants (SC) which calculate statistics, capacity etc. for the building and make drawings for the concrete work. Architects design further on the carpentry drawings, which in turn together with the SC drawings, constitutes the decision premises and basis for the drawing of the technical disciplines. The empirical study support (see also Andersen 2016) that this decision-making system is based on an underlying material-technology order of dependency. This order (rationale) for the

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decision-making system in traditional design has, however, to a high degree been an implicit assumption. However, the new empirical development makes it possible to reveal this order and to make it explicit. It makes a reconstruction of the order and its suppositions possible, but now in the new context of integrated concurrent design and engineering and autonomous experts and their reciprocal communications and dialogues. The reconstruction provides for both a basis for fulfilling the potential for increased creative interaction and a decision-making system that triggers increased process control and reduced design errors.

The first part of the paper uses three empirical cases to discuss the practical problems of how to organize for increased creative force and efficient decision making in the design process. The middle part of the paper discusses the theoretical approaches that illuminate the problem to be addressed: First, it discusses language-action theory and the eighth flow approach in an extended theoretical context that highlights the epistemological suppositions regarding holism and individualization. Then follows a presentation of modern organizational system theory that strengthens our notions of autonomous (autopoietic) specialized disciplines that are both "closed" to each other and that must at the same time communicate and interact as a community. The paper's final section presents a theoretical proposal based on phenomenological analysis where both the creative processes between specialists and an efficient decision-making system are derived from analyses of the material-technological order of dependencies in building processes, as reflected in the logic of materialized models and drawings in design. The paper outlines, finally and in accordance with the purpose of the research, some implications of the material-order approach for the organizational layout of the design process.

THE EMPIRICAL CASES: COMPLEXITY AND POTENTIAL

The main empirical case involves the construction of a hospital. There are two support cases based on cross-sectional studies from the stationary manufacturing industry. The study of the hospital project was funded by contractors, consulting firms, and the builder. Support cases are from an ongoing project, "INPRO," funded by the Norwegian Research Council (2014–2017). The research method in the hospital project was formative research (observations, interviews, and workshops) and process tracking: deficiencies in the work substrates (drawings, work plans etc.) of the physical construction was traced to the engineering and design phases, and deficiencies in the engineering to the design phase. The data was subject to a phenomenological analysis. The research method in the support cases was based on interviews.

In **case 1**, the hospital project used Integrated Concurrent Engineering (ICE) and Virtual Design and Construction (Chachere, 2009) with collocation. In the ICE session (both formal and informal), the activities were parallel and integrated and participants constructed their object areas using meaning-centered communication (Clegg and Baily, 2008; Luhmann, 2002, Andersen 2016), in which the participants reciprocate and through iterations build on each other's ideas, adding meaning on meaning. Meaning-centered communication is fundamentally unpredictable; participants understand their own contribution by virtue of what the other answers (ibid). The participants have mutually enclosed knowledge domains (distributed knowledge), but are at the same time communicating to create common emergent meaning corresponding to the joint product of the process.

Some of the disciplines organized themselves at **discipline** level (cf. SC, Electrical Consultant (EC)) using their own separate meeting arenas, but it was large variations between companies; and general ambiguities about how the discipline systematically could reinforce and use its resources in the project. The communication in the meetings where the discipline discussed their tasks in the different multidisciplinary teams had anyway elements of meaning-centered communication and emergent processes. The organization of the design process was essentially **interdisciplinary**. The project was divided into parallel, working, multidisciplinary teams organized according to different thematic parts of the building based on clusters of interconnected, determining functions: entrance hall, auditorium, operating rooms, etc.). The specialists communicated in the multidisciplinary teams in the interdisciplinary interfaces with limited access to each other's knowledge. What is happening between the disciplines, however, cannot be understood solely by a notion of interface. The processes in each multidisciplinary team take the character of a separate, closed, emerging community creating its own unique and unified object. The multi-disciplinary teams were coordinated on the **project** level by a core group. Also, work at this level takes the character of something substantively and as more than a coordination of the multidisciplinary thematic groups. The study showed an interdependence between the emergent processes of levels: creative expertise at the discipline level is, for example, a prerequisite for creativity in interdisciplinary dialogues and vice versa. In accordance with ICE was the communication form in the hospital case marked by equal dialogues and roles in decision making: all subjects and disciplines counted on an equal footing both at the multidisciplinary level and at the project level.

Case 2 deals with the design process for the construction of oil rigs. The company wanted to concentrate the work of the disciplines into multidisciplinary teams and intensive interactive processes. The new way of working thus began with a phase of system design going through the entirety of a single rig construction. Then, inspired by the development methodologies of Scrum and Agile approaches, the company developed a process in which a multidisciplinary team sequentially works through modules extended to physical subareas of the rig construction. The areas of the rig as a whole was not processed in parallel and integrated. This implied that the project level was not included as a simultaneous and dynamic element in the process. The organization with a single team that worked through the whole construction created a great demand for generalist skills. **Case 3** deals with the processes of a design unit in a shipyard, originally organized top down and with a process in which the disciplines followed in a sequential, linear order. Then the unit changed to a flat structure with a multidisciplinary team organization - with each team working with one project. The new culture was based on dialogic and open processes with emphasis on integrated joint expertise, generalist competence, and knowledge sharing.

Out of the three cases, it is Case 1 that has the most developed and complex process with a parallel and open interplay between all three levels: discipline, multidiscipline, and on the level coordinating the multidisciplinary teams: the project level (compact complexity). On the multidiscipline level, the joint product is an evident object (the restaurant, the auditorium, etc.). The project level gets the architect's purpose to appear based on what we in the continuation shall call structural material. One can assume that the most intensive form with the highest innovative force takes place when all three levels concurrently and in mutual interplay produce emergent contributions.

In Case 1 during the building process, defects in the work substratum (drawing, models and plans) were revealed, and also how the emphasis on dialogue between equal participants resulted in a vacuum in the common decision making process (Andersen, 2016). The pattern of the defects made it possible to track the causes of the errors back to the vagueness and lack of order in the decision-making structure (and tendencies to a decision vacuum) in the design and engineering phases (a split turnkey contract used in the project helped to highlight the matter).

THEORETICAL APPROACHES

LANGUAGE ACTION THEORY – ORGANIC KNOWLEDGE AND HOLISM

Language Action Theory is especially used in connection with the Last Planner System (Ballard, 2000). The theory focuses on how people in organizations work through speech acts. Speech acts bring into focus "assertions, assessments, requests, promises, and declarations" (ibid: 1169) and how those as performative utterances "do things" in the real world (Austin). In the Language Action Theory, the coordination of actions takes place primarily in the language in use. Accordingly, organizations ought to be organized around members' conversations and those conversations' ability to create binding unity and harmonized actions. In this theory it is the pragmatic relationship in language that is in focus; that is, the relationship between the subject and the utterance.

The Language Action Theory may be interpreted according to Wittgenstein's (1881–1951) language games, and the tradition as continued in socio-cultural learning theory (Wygotsky, 1978), including Community of Practice (CoP: Lave and Wenger, 1991). Each CoP grows out of specific practices, such as the work communities for machine repairmen, web designers, etc. The CoP approach is also used in the analysis of modern specialized and knowledge-intensive organizations (Carlile, 2004). The organization or project is determined as a community of practice with a unified and integrated knowledge and competence base. This kind of process may be further interpreted by the theory of organic organizations; see for example Burns and Stalker (1961). An organic organization adapts to changing and unpredictable internal tasks in accordance with unpredictable external environments. Organic organization requires employees with broad expertise; the employees are generalists and can work with a wide range of challenges, working in a flat organization with teams of changing compositions, etc. It can be contrasted with a mechanistic organization (Parrish, 2014: 1169), based on comprehensive, specialized work; but in a fixed form and where each specialist's expertise is isolated from the others and tied down to a specialized domain. Language Action Theory is here interpreted in light of an organic holistic tradition where generalist skills (whole) are developed across and above the specialist expertise (parts). Cf. Cases 2 and 3 in the empirical section

THE EIGHT FLOW AND INDIVIDUALIZED KNOWLEDGE

"Individualized" approaches emphasize a conceptual strategy that highlights the individual's and single parts' autonomy in an organization or a project. The theoretical contribution of the eighth flow (Pasquire and Court, 2013) is about human understanding and a corresponding expansion of Lean Construction discourse about physical flows (Koskela, 2000). The eighth flow assumes that knowledge is distributed and that individual people have their unique perspectives, experiences, and understandings related to the network of flows (ibid: 5). According to the eighth flow, the individual´s performance of work is situational and requires the independent use of knowledge, including insight into the relationships of work - or in other words, it requires understanding. The subjects may increasingly create a common understanding through planning processes that integrate distributed knowledge. The assumption of the eighth flow about distributed knowledge focuses on language's semantic side; the relationship between the term (utterances) and what is termed.

The theory Communities of Knowing (CoK: Boland and Tenkasi, 1995) is about communication between separate, different, and knowledge-intensive communities. The knowledge of each community is based on verbalized and explicit cognitive knowledge (as opposed to CoP). Each CoK, has a "paradigmatic" foundation and a shared pre-understanding that gives members a common frame of reference. In highly complex and specialized organizations, such as a modern construction project, each discipline is a CoK. CoK theory distinguishes between perspective-making, perspective-taking, and perspective-presentation (Litchfield and Genty, 2010). Each community creates (strong) perspectives through increased access to narratives and the systematic development of the base of experience (empirical experiments). Perspective-taking is all about taking the perspective of others to see the situation from the other´s point of view as when one discipline takes the perspective of the other. The disciplines' perspective-making, perspective-presentation, and perspective-taking are prerequisites for interdisciplinary communication and dialogue.

In the eighth flow and CoK, individuals and disciplines are independent entities with mutually "closed" (specialized) experiences and knowledge bases. What is common between the units is, however, insufficiently determined. What, for example, providing different individuals a unified outer experience so they can build something common in real external production (construction, models, etc.) - beyond a cognitive plan level? And how is it that the seven "physical" flows are connected with the common reality "out there"? Both the eighth flow and CoK examine the language's semantic dimension without further determining the outer world as the signs and knowledge refer to. Both are limited to linguistic theory and semiotics (Saussure 1974) where the reality outside language melts in the air.

MODERN “ORGANIZATIONAL SYSTEM THEORY”

This theory (Luhmann, 2000) is intended to transcend the dichotomy between holistic and individualistic (atomistic) theories. An organization’s members’ mental "systems" differ from the organization as a social communication system (ibid). Individuals have freedom and can (as mental systems) connect to and from each communication system. The communication system is differentiated into autonomous part-systems by function- or system differentiation. The systems are operationally closed and autopoietic in the sense that each system creates and recreates itself out of its own elements and its own internal logic (ibid). When the systems communicate, they do partially penetrate each other (interpenetration) – as when disciplines interact. To organize each system involves developing general decision-making premises, such as conditional- and target-programs, communication routes, and permanent membership (individuals), which stabilize and make the autopoiesis of each system possible. Systems theory helps us to determine autopoietic “parts” – the individual disciplines in a design process can develop their own programs (plans) and strong perspectives that they can use in the interdisciplinary dialogues on the thematic level or the dialogues concerning the joint project program. According to systems theory, there is a communication network that keeps the part-systems together through "mutual adjustment". The theory, however, also creates an opening for determining an independent autopoietic communication system with its own content at the interfaces where the disciplines meet and cooperate.

The “organizational system theory” grasps essential features of the empirical process described on the basis of Case 1 in the empirical section; cf. the observation of closed, autopoietic, emergent, and emerging processes in communication arenas at all levels: the discipline level, multi-disciplinary level, and "project level". The content of, for instance, the core group´s work could not be described simply as handling interfaces, as coordination, network formation, etc., but must be determined as a separate emergent communication system with its own content sui generis. But at this point, we also meet the limitations of the theory: First, that all systems are equal corresponding to an polycentric decision-making system. Second, that the theory is a communication theory about the emergence of new levels of order of **social meaning.** Similar to the previous theories, this theory is a “social relational” theory. Husserl, the founder of phenomenology, developed another theoretical base that presupposes that the outer material and technological object-world allow for the human subjects to come into contact with each other. The Corresponding phenomenological method involves analysis of intentionally mediated deep structures in the outer phenomenon world (Zahavi, 2003). Regarding the need to anchor the theories on a metaphysical level, see Koskela and Kagioglou 2006.

THE MATERIAL -TECHNOLOGICAL ORDER

The classical phenomenology implies a change of scene in the sense that we must anchor organizational and project theory at a material-technical order and material dependencies. This order offers an answer to the question of how individuals' contributions are interrelated and how the system contributions are included in one another in practical life. What is it specifically that gets contributions from the amount of specialists, functions and sub-functions, to be interconnected and united in practice in the outer empirical world?

If we focus on the entrance of the hospital, its lighting fixtures are hung in special places to provide the desired illuminations, the reception is positioned to "communicate" with the front door and further into the building, etc. The single functions are included in a social context to make sense to the user of the building. However, the functions of meaning **do not** float in the air, but are functions of different types of materials. The partial functions are arranged in material causal-chains which lead to features and user-functions: "here it is good lighting", "this room was cool in the summer heat - good ventilation!" The ventilation system is positioned at a place separated from the electrical system. The social context can be extended through user-functions over into a material context - and further into a deeper material order: when user-functions should be arranged, this happens using what I propose to denote **structuring material**: lighting, ventilation, piping, etc. are fastened, build into or lay down in the floor, walls, and ceiling (Andersen 2016). This is the building's "skeleton", the constructional elements (concrete, wood, steel structures) which make it possible to give the other material and individual functions a fixed order, coherence and continuity in space and time. Structural material, logically and in time, precede the other material and functions. One cannot attach the ceiling in the cables. It is the unity of the two dimensions that coordinate each "side" of the process: a social and a material side, and that gets the specialist´s contributions to something coherent.

It is, based on this approach, the structuring (formative) material that safeguards the "whole" in the process in outer reality, and it is this material that gives structure to the arrangement of the materials. It is first and foremost the architect's task, responsibility, and specialty to preserve and develop the appropriate linkages of meaning; user-values and the corresponding value creation of the building. As an extension of this, they also have a responsibility for the good order and coordination of the user-functions anchored in the physical material contribution of other disciplines.

It is further the Structuring Consultants (SC), structural engineers (on site) and normally the concrete subjects and carpenters who are specialists in and have responsibility for structuring material (the building's skeleton). When architects, SC etc. (what can be termed the "structuring subjects-axis" – or "structuring-axis") take their role, they create by realizing the purpose and tasks of their own subject at the same time primarily coordinating guidelines for the other subjects like the technical subjects. All subjects have their specialist expertise; the structuring-axis from architect to SC and on to concrete work and carpentry have in addition a general structuring competence integrated into their own specialist expertise which is about to coordinate interfaces between structural-axis and other subjects (this competence is normally most explicitly developed by the architect subject).

The rest of the disciplines must not only take the other disciplines' perspectives, but especially the perspective of the structuring-axis: they must e.g. familiarize themselves with the architect's perspective as it concerns the material effects for the customer (user).

Structuring material makes up the concrete totality and is the entrance to the project perspective (Andersen, 2016).

The transition from the disciplinary to the multidisciplinary level makes the logical order of the material evident: the team that create the common product or object (e.g., the restaurant) must first sketch or create the physical "skeleton", then the electricians hang up their part, plumbers append the piping, etc. The teams products (restaurant, auditorium etc.) are also in the last instance linked together through structuring material. Also on a project level, the structuring material contributes so that the process can be understood as an autopoietic process similar to the creation of a unified and common product or object. The material order and the distinction between structuring and specific materials adds a general basis for a more differentiated concept of “structured emergence,” “structured meaning-centered communication,” and “structured collaboration.”

ORGANIZATIONAL LAYOUT

The material-order approach unites a strong dialogue orientation and an efficient decision-making system by using structured collaboration: questions concerning the interface between a structuring-axis (decision-axis) and other subjects belong in the last turn to the structuring-axis (decision-axis) specialty. These subjects are responsible for primary coordinating guidelines. If dialogues between disciplines on issues at the interface have not in itself led to agreement and decisions, then the decision-axis or the part of the axis involved decides based on its expertise. The principle is, however, "dialogue first”. Generally on the arenas in the project at the multidisciplinary and project level, representatives of the decision-axis are used as group leaders and coordinators, to draft plans, etc.

According to the material-order approach, there should be a separate organization on the discipline level (for each discipline), for each multidiscipline team, and on the project-level (core group) to generate their own programs (operational plans), develop internal and external communication channels, and stabilize their manning. Based on the organized discipline level the discipline-actors should develop **strong,** situation-specific, **discipline-perspectives** directed towards tasks at the multidisciplinary team level and correspondingly at the project level.

The main task for the decision-axis (e.g., in the core group) is to create social coherence and physical cohesion for the project by using the idea of structuring material (in accordance with a separate autopoietic system) by developing a plan. The plan must be developed in dialogue with representatives from each multidisciplinary team and representative that take responsibility for the individual discipline’s perspectives so that these perspectives and interests are integrated in the plan. It is e.g., the architect’s task after the meeting in practice to further develop the idea of the building through the structuring material as an assumed autopoietic system - still in dialogue with the other disciplines or subjects. The task of the rest of the decision-axis is further realization of the system - in the end as a physical material building.

The principles of organizational layout outlined above are the same with regard to the various stages in the construction project. The material-technological order of dependencies in the physical building processes is e.g. reflected in the materialized models and drawings in engineering and in design.

DISCUSSION

Recent development in the implementation of design processes has made visible aspects of empirical reality that challenge basic assumptions of existing theory. In the paper, some actual theories has been divided into organic (holistic) and individualizing approaches. The organic theories illuminate processes related to the whole and community, while the individualizing theories address processes related to the autonomy of parts, individuals, disciplines, etc. The paper suggests a material-technological order approach that mediates between autonomous (autopoietic) parts and joint production kept together by forming and structuring material. The material order is the **possibility-condition** both for the development of competencies at the levels of discipline, project, and multi-discipline, and at the same time for an effective decision-making system that takes effect when the dialogical processes do not in themselves lead to consensus and agreed decisions. The material order approach is proposed as an expansion of the Lean Construction discourse including an expansion of the linguistic theory to phenomenological-material analysis. Ongoing and future research of this approach would clarify the interactions between discipline, multidisciplinary, and project levels, using empirical comparative implementation studies.

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EXAMINING THE CRITICAL SUCCESS FACTORS IN THE ADOPTION OF VALUE STREAM MAPPING

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ABSTRACT

Value Stream Mapping (VSM) is a functional approach to reorganizing production system in line with lean vision. It has been applied in many sectors to improve performance. However, there are several factors that need to be considered while implementing VSM in practice. This paper presents a literature review of the Critical Success Factors (CSFs) in the implementation of VSM across five different sectors: manufacturing, healthcare, construction, product development, and service. The review covers the peer-reviewed journal articles on VSM in Scopus from 1999 to 2015. A four-stage search criteria is designed to refine the publications. 14 CSFs are identified through the deep analysis of the five sectors, and six of them are common success factors, namely, empowered inter-principle lean team, top management, organizational culture, theory refinement and integration, resource availability and communication. The differences of the factors in five sectors are also discussed in this paper. The main limitation of this study is related to the source of the selected papers because conference papers are excluded in this review. The findings of this study provide a good basis for industry practitioners to effectively implement VSM.

KEYWORDS

Value stream mapping, critical success factor, cross-sector review

INTRODUCTION

Value Stream Mapping (VSM) is a process improvement technique that aims to maximize final customer value by identifying and eliminating waste in entire value chain (Rother and Shook 1999). VSM has been proven to be able to provide significant

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improvements in efficiency, productivity and service quality, and to lead to a reduction in production lead time as well as production work process. Although a variety of successful VSM cases have been demonstrated in a number of empirical studies, the implementation of VSM has still encountered several considerable challenges. Therefore, there is a need to identify the Critical Success Factors (CSFs) in the implementation of VSM. Through a better understanding of the CSFs, project managers can conduct the corresponding solutions to facilitate the successful implementation of VSM in practice. Limited research work has been done to recognize and classify the CSFs in the adoption of VSM. Moreover, the different contexts of sectors are not seriously respected during CSF development. Therefore, this paper aims to (1) identify the CSFs through a comprehensive and systematic literature review, and (2) analyze and classify the identified CSFs across different sectors.

RESEARCH METHOD

A comprehensive search through the relevant literature was conducted for the years from 1999 to 2015. In this study, articles from journals were identified, analyzed, and classified. Since VSM has been implemented in a wide range of sectors, it is necessary to search through a wide range of studies. The scope of the search is not limited to specific journals. Consequently, Scopus was selected as a searching platform to provide a comprehensive bibliography of the literature on VSM. To acquire a more elaborated understanding of VSM related research, the search for article was further refined by four stages:

In stage 1, document search was conducted under "keywords/title/abstract". Keyword "lean" was searched with value stream mapping, value stream map, value stream, VSM, value process, value stream management, and value stream analysis. The search was further limited to article, article impress and review of the document type. The initial search yielded 280 articles.

In stage 2, a brief review of the abstracts and contents of these papers in stage one was conducted to filter out the highly-related articles. After the two-stage search, a total of 90 VSM-related articles distributed over 33 different referred journals were identified.

In stage 3, the manual search was served as a means to complement the possible omissions of VSM research articles archived by the search engine. After the three-stage research, a total 97 articles were identified and coded by analyzing applied sectors. VSM implementations were classified into five sectors, including (1) manufacturing (72 articles), (2) healthcare (11 articles), (3) construction (8 articles), (4) product development (4 articles), and (5) service (2 articles).

In stage 4, a qualitative content analysis was adopted. In this method, the emphasis is on lensing the articles which potentially suggested key factors for efficient VSM implementation in five sectors. Finally, 25 articles conducted in various sectors were identified. Each article was carefully reviewed, and the CSFs for VSM implementation were identified.

RESULTS

Based on the selection criteria, 25 articles were investigated in this study. Table 1 shows the distributions of the articles under the categories of implementation sectors and lists the 14 CSFs for VSM implementation. These factors were 'empowered inter-principle lean team (a)', 'top management support (b)', 'training and education (c)', 'theory refinement and integration (d)', 'organizational culture (e)', 'communication (f)', 'IT support (g)', 'resource availability (h)', 'stage control (i)', 'manageable size (j)', 'skill and abilities (k)', 'strategies alignment (m)', 'standardization (n)', and 'tools and techniques (o)'. Each of the CSFs is discussed in detail in the following section.

EMPOWERED INTER-PRINCIPLE LEAN TEAM

The effective implementation of VSM requires building an inter-principle lean team with roles in accordance with what the VSM technique advises. In addition, the decision makers in the project team should be empowered to make effective decision.

TOP MANAGEMENT SUPPORT

This factor an essential CSF for VSM implementations. Successful implementations require management involvement and top management support in decision making (Serrano Lasa et al. 2008). The roles of leadership in VSM implementation include developing a general understanding of the whole process, establishing a reasonable goal for work improvement, educating staff during handover meetings, explaining their work during the mapping exercise, and communicating strategy to all employees (Cookson et al. 2011). All of the studies in the five sectors showed a high degree of consensus on the critical role played by strong top management support.

TRAINING AND EDUCATION

Lean knowledge training is another important key factor for successful VSM implementation. Serrano Lasa et al. (2008) confirmed a positive correlation between the investment of training and the achievements of the future state map. Dal Forno et al. (2014) indicated that the cause of issues related to people in VSM implementation was training shortage**.**

THEORY REFINEMENT AND INTEGRATION

'Theory refinement and integration' is the most frequently cited CSF for VSM implementation. The existing VSM applications mentioned in many cases are not complete because of the gap between theory and practices (Serrano Lasa et al. 2008). In order to fully release the benefits of VSM, incompleteness of VSM theory itself has been addressed by refining VSM theory (Serrano Lasa et al. 2009; Yu et al. 2009) and integrating the related ideas , such as simulations and IT(McDonald et al. 2002).

ORGANIZATIONAL CULTURE

A supportive organizational culture defines the values that establish the focus and end goal of collective efforts. According to Mi Dahlgaard-Park et al. (2006), the definition of organizational culture comprises many facets. One cultural aspect is customer satisfaction, which emphasizes on building a mutual understanding of the value from the viewpoint of customers. Collaboration is also another fundamental aspect of a shared value culture. This is because VSM implementation requires a collaborative culture to interact, exchange and share the values with everybody's participation (Saad et al. 2006).

Table 1: CSFs for VSM implementation in five sectors

Sector	Articles	CSFs of VSM													
		a	b	c	d	e	f	g	h	i	j	k	m	n	o
Manufacturing	(Abdulmalek and Rajgopal 2007)				*										
	(McDonald et al. 2002)				*										
	(Seth* and Gupta 2005)		*				*						*		
	(Serrano et al. 2008)	*	*	*	*			*		*	*	*			
	(Lian and Van Landeghem 2007)				*										
	(Chen et al. 2010)				*										
	(Serrano Lasa et al. 2008)				*			*							
	(Singh et al. 2011)	*		*	*										
	(Gurumurthy and Kodali 2011)				*										
	(Serrano Lasa et al. 2009)			*	*										
	(Lu et al. 2011)				*										
	(Bertolini et al. 2013)				*										
	(Saad et al. 2006)	*	*			*			*			*			
	(Dal Forno et al. 2014)	*	*	*		*	*			*	*	*	*		
	Subtotal	4	4	4	11	2	2	2	1	2	2	3	2	0	0
Healthcare	(Carter et al. 2012)		*				*				*				*
	(Michael et al. 2013)						*								
	(Cima et al. 2011)						*								
	Subtotal	0	1	0	0	0	3	0	0	0	1	0	0	0	1
Construction	(Yu et al. 2011)	*	*	*	*									*	
	(Nath et al. 2015)			*				*							
	(Arbulu et al. 2003)	*		*			*		*					*	
	(Yu et al. 2009)	*	*	*	*	*								*	
	Subtotal	3	2	4	2	1	1	1	1	0	0	0	0	3	0
Product development	(Ali et al. 2015)				*										
	(Tyagi et al. 2015)					*									*
	(Tuli and Shankar 2015)						*								
	Subtotal	0	0	0	1	1	1	0	0	0	0	0	0	0	1
Service	(Radnor et al. 2006)		*			*	*		*				*		
	Subtotal	0	1	0	0	1	1	0	1	0	0	0	1	0	0
	Total citations	7	8	8	14	5	8	3	3	2	3	3	3	3	2

COMMUNICATION

Clear and effective communication at all levels of an organization is necessary before and during VSM implementation (Dal Forno et al. 2014). Communication comprises two aspects: involvement of all employees and equal input from all the team members. The involvement of all employees is the foundation of mutual understanding and clear communication occurs within the entire organization (Radnor et al. 2006). Equal input from all the team members encourages group decision making rather than any exclusive dominant.

IT SUPPORT

IT support can be categorized into three levels. Level 1 is a group of software tools that solve the static issues of VSM, e-VSM and IGRAFX VSM and other Excel and Visio templates are used to help the users to draw the map and conduct basic calculations (Braglia et al. 2009). Level 2 is a connection with Enterprise Resource Plan (ERP) system for obtaining, comparing and processing data in terms of the production flow (Serrano Lasa et al. 2008). Level 3 is a Building Information Modelling (BIM) and Virtual Reality (VR) supported collaboration for the inspection, assessment, repair and 3D visualization of the work flow (Shou et al. 2015; Wang et al. 2015; Wang et al. 2016).

RESOURCE AVAILABILITY

Resource availability is a primary concern in VSM. Financial and human resource are the two resources usually mentioned aiding actual VSM implementation. This is because finance enables all useful provisions such as consultancy and training can be made (Saad et al. 2006). Human resource is a type of resource requiring a committed delivery team work on VSM implementation with a dedication of time (Radnor et al. 2006).

STAGE CONTROL

Effective control of the stages of VSM has been mentioned many times in manufacturing sector. According to Serrano Lasa et al. (2008), VSM implementation in each stage should be carefully measured and controlled for correct decision making.

MANAGEABLE SIZE

Selection of a manageable size project attracts much attention in manufacturing and healthcare sectors. The selected project should ideally reveal the key issues in process and must be aligned with the objectives of the organization (Dal Forno et al. 2014; Radnor et al. 2006).

SKILLS AND ABILITIES

The specialists' skills and abilities for conducting the VSM activities in process were mentioned in manufacturing. This is because some of the lean techniques applied for future state improvement have some requirements to employee skills and expertise, especially improvement link to information technology (Dal Forno et al. 2014).

STRATEGIES ALIGNMENT

In order to reach long-term success and improve performance, VSM implementation must be aligned with the company strategy. Understanding the strategic context of a VSM program is essential to maximize the value for process improvement (Dal Forno et al. 2014).

STANDARDIZATION

This factor was mentioned in the construction sector as building process was full of variety and uncertainty (Yu et al. 2009). Standardization is recommended to eliminate handover problem which caused by variations in construction processes.

TOOLS AND TECHNIQUES

Appropriate tools for data measurement are required for reducing the issue of low data accuracy. For example, Ali et al. (2015) utilized appropriate techniques to eliminate wastes in healthcare environment.

DISCUSSION

Understanding and identifying the CSFs are essential to increasing the chances of a successful implementation of VSM. This study indicates that the CSFs identified are generally relevant to the VSM implementation projects across sectors. However, it is also found that the projects engaged in VSM implementation in different sectors differed significantly in performance concerning some CSFs. These phenomena are discussed comparatively in the following subsections.

THE CSFS IN THE ADOPTION OF VSM

According to Table 1, two of the fourteen factors were mentioned in at least four sectors, namely ‘top management support’ and ‘communication support’. Factors of ‘empowered inter-principle lean team’, ‘theory refinement and integration’, ‘organizational culture’, and ‘resource availability’ are in the second tier. This result is nearly consistent with the work of Saad et al. (2006), who evaluated the four factors (‘leadership and management’, ‘financial capabilities’, ‘organizational culture’, and ‘skills and expertise’) and rated them as most critical to the success of lean implementation. However, factors such as ‘stage control’ and ‘standardization’ were only cited in one sector.

VSM TRENDS ACROSS SECTORS

It is not surprising that most of the research that was examined on the subject of CSFs for VSM implementation was conducted in manufacturing. This is because VSM is emerged from lean manufacturing theory and has been widely adopted according to the review results. Lean concept has become a buzzword in the healthcare sector in the last few years because of the concern to improve organization performance. There were three studies examining the CSFs for VSM implementation in the healthcare sector, while four studies in the construction sector. Interestingly, there has only been limited relevant CSFs research conducted on sectors of service and product development, although VSM has started making inroads in both sectors. Future researchers can more focus on investigating the CSFs in sectors except manufacturing, especially service sector, to see whether there are any differences.

DIFFERENCES AMONG THE FIVE SECTORS

This study also shows several differences of CSFs for each individual sector. The factor 'theory refinement and integration' received the highest attentions in the manufacturing sector while less in the other four sectors. The underlying reasons can be twofold. Firstly, the incompleteness of VSM theory was recognized after many of the implementations were conducted in the manufacturing sector. For example, VSM is a static image of the value stream, and only the most obvious changes are suggested (Lian and Van Landeghem 2007). In addition, VSM fails to map value streams characterized by multiple flows merging together (Dal Forno et al. 2014). Trial and error method, which employed for continuous improvement to accomplish the desired level of future state, causes waste of resources (Tyagi and Vadrevu 2015). Therefore, in order to achieve the full functionality of VSM, the incompleteness must be overcome by refining VSM theory and integrating related ideas. Secondly, the VSM implementation in the other four sectors is still in the initial stage, and current research is mainly focusing on how to adapt the existing VSM theory to the corresponding domain context.

The CSFs in the construction sector have a lot of overlaps when comparing with the manufacturing sector. The construction sector has a significant development on project management theory since the concept of Transfer-Flow-Value (TFV) from lean theory was introduced (Koskela 1992). The construction sector has recognized the functionalities of VSM, and used it as an effective lean tool to improve process performance. It is acceptable to claim that VSM has a decent implementation in the construction sector. However, the full capability of VSM has been hindered by the negative effect of variations in construction projects. This is the reason why "standardization" was a critical technique and referred as a CSF for VSM implementation in the construction sector. Future VSM implementation should focus on the standardization aspect for construction projects.

There is no repetitions of the CSFs in product development sector as compared with other sectors. All the three articles were published in 2015. Although the samples identified for CSFs analysis are not enough, we can conclude that the discussion of the CSFs just starts in product development sector.

There is only one article was identified based on the selection criteria in the service sector, although a little more research can be found when we only consider the 'lean' keyword in stage 1 of research methodology. VSM application in this environment is still emergent, with a focus on a small volume of projects, and considering only one or two stages of the VSM implementation. There is a need for further examination of the explicit and directed application of the VSM to the pure service environment.

In this regards, it would be reasonable to conclude that VSM implementation in manufacturing sectors is several years advance than that other four sectors. VSM adoption case in other sectors could benefit from the widely used experience in manufacturing.

CONCLUSIONS

This paper presents the results of a study on CSFs for VSM implementation in five sectors. A total of 14 success factors were identified from the literature review. This comparative review of the literature has shed light on common CSFs for VSM implementation. It was concluded that there were six common success factors across the five sectors.

Although this paper cannot claim to be exhaustive, it does provide a comprehensive review of the CSFs for VSM implementation. The results presented in this paper have several important implications for VSM practitioners and researchers alike.

The limitations of this study are the fact that only journal articles were approached in this review. Conference proceedings are not considered which may offer a wider view on issues related to the impact of critical factors on VSM application. Moreover, relatively few articles could be found for most sectors, except for manufacturing. Readers should be cautious in interpreting the results of this study. Further research is needed to investigate the disparities and the reasons underlying for cases of different sectors.

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WHERE LEAN CONSTRUCTION AND VALUE MANAGEMENT MEET

Muktari M. Musa [1], Christine Pasquire [2], and Alan Hurst [3]

ABSTRACT

The lean construction (LC) community's key vision and goal is to provide value, yet they are increasingly challenged with understanding and dealing with the concept of value, with reports that value is one of the weakest points. Regardless of the previous studies and contributions already made on the concept of value in LC, the absence of a consistent understanding of value has resulted in misperceptions and indistinct boundaries with other construction value-related disciplines. Without a consistent understanding of value, the full potential of applying value-established concepts will not occur. Thus, the study of different concepts in construction will open new opportunities to deliver value in the future.

Literature reviewed only revealed a small number of interdisciplinary comparisons of Lean manufacturing and LC with value management (VM)/value engineering (VE) on value. Secondary data was used to present an in-depth comparison of the principal points of the current practice and theories of LC and VM, which are seen as ways to improve the delivery of value to clients and building users. The study revealed a range of similarities at a high level, which could easily point to an early conclusion that LC and VM are interchangeable, leading to the same goal of value delivery and shared misapplication of cost reduction techniques. However, a more detailed examination indicates significant differences in the philosophy and scope in different areas, including project timing, practitioner duties, and areas of practice which could complement each other.

Also the study identified that LC is a broader philosophy which covers more aspects than VM, it is evident that LC has advanced over the years towards discussions on the concept of value. The current work in LC on value relies less on other construction value-related disciplines such as VM, VE and partnering. Furthermore, LC literature still views value as a confusing concept associated with different interpretations, forming the basis

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of its understanding. The study established that value plays a central role in both LC and VM. Their combination could offer great synergy regarding the concept of value.

KEYWORDS

Lean Construction, Value Management, Value, Value-related disciplines, Integration.

INTRODUCTION

In recent times, there has been increased focus in current lean construction (LC) literature towards understanding the management of value, which is the end-goal of all construction projects (Emmitt et al., 2005; Salvatierra-Garrido and Pasquire, 2011). The LC community's key vision and goal is to provide value (LCI, 2016b). Although understanding, managing, and dealing with value has become a topic of growing importance when applying lean thinking by stakeholders, it is reported to probably be the most difficult to approach in managing construction projects and one of the weakest points of LC (Bertelsen, 2004; Bertelsen and Koskela, 2004; Emuze and Saurin, 2015).

Munthe-kaas et al. (2015) further argued that the management of value in construction is difficult and unpredictable due to the change of perspectives and nature of human beings. Recently, researchers have asserted that if value is not agreed upon initially in construction, then it will be challenging to maximise it (Drevland and Lohne, 2015). However, the agreement of value parameters and the use of the concept of creating value for the customer as the fundamental purpose of a project has contributed to the success of many projects. Additionally, the importance and achievement of improved productivity and client/user satisfaction has been recognised (Emmitt et al., 2005; Munthe-kaas et al., 2015; Salvatierra-Garrido et al., 2009).

The absence of a consistent understanding of value in construction has resulted in misperception and indistinct boundaries with other construction value-related disciplines. In agreement Emuze and Saurin, (2015) reports that discussions on value raise contradictions that impair a general understanding of the concept that could find alignment in contemporary thinking throughout a number of disciplines. Mossman (2013) asserted that value is a concept that requires continual updating and adjustment. In this respect, understanding the full potential of the management concept of value requires integration and iteration, considering its complex nature; thus, the study of different concepts in construction opens new opportunities to deliver value in the future (Kevin and Fadason, 2012; Salvatierra-Garrido et al., 2009).

The extensive progression of the concept of value in construction can be accredited to disciplines like LC and value management (VM). Seni, (2007), clearly emphasised the need to know about value in VM and other value disciplines. It is imperative for value to be explored in concepts such as partnering, VM, and other disciplines, like lean, as it has been found that the application of the concept of value is predominantly a part of these concepts (Wandahl, 2015). Literature reviewed only revealed a small number of interdisciplinary comparisons of Lean manufacturing and LC with VM/value engineering (VE) with the aim of identifying synergy in the way value is understood and delivered.

Previous researchers have documented that lean manufacturing and VM are established disciplines with complimentary merits and flaws; it is claimed that lean manufacturing tools and techniques may be used to improve VM studies and vice-versa (Nayak, 2006; IVM, 2015b).There have been many varied attempts to develop a clear understanding of the conceptual and practical perspectives of value in the IGLC community. A prevailing perception of value as a 'thing' as opposed to an emerging and dynamic phenomenon has had a varying and restricting effect on construction. High-level discussions and contributions of theories and management concepts, such as VE, VM, and lean thinking, etc., has led to fragmented individual perceptual representations of value. Consequently, the concept of value remains a rich field to explore (Salvatierra-Garrido et al., 2009). This paper considers LC and VM, as ways to improve the delivery of value to clients and building users.

METHODOLOGY

The study leading to this paper adopted an extensive and multi-disciplinary literature review in an attempt to bring together construction value-related concepts towards a consistent understanding of value according to the purposes of LC. A study aimed at comparing LC and VM views towards the concept of value was carried out to identify synergy in the way value is understood and delivered. To achieve a more general context to gain a more detailed understanding of the topic, a comparative study was conducted with high quality secondary data, which covered the intended population that focused on studies that shared the same view through identification of the main features of current theory and practice of LC and VM in the context of value in construction.

Several academic databases, including Scopus, Proquest, and Google Scholar, were searched in order to identify peer-reviewed journal articles, conference papers, and priority books. The search criteria primarily included the period of publication, key terms, and ranking criteria, with the period of publication set at 26 years to date because LC is a newer concept in construction management.

The articles selected to form the database of this study were chosen based on two considerations: context (i.e., construction/project management) and relevance (i.e., both academic/research papers and books related to the value concept). From a sample of 35 papers and books identified as related to value, the following concepts were documented: LC, VM, concept of value, value-based management, partnering, etc. This paper aimed at identifying a clearer path for a larger doctoral research study, where the result of this secondary data will be used to frame part of the questions for interviews to help confirm the initial findings. This study only considered secondary data due to lack of primary data.

THEORETICAL LITERATURE

VALUE IN THE CONTEXT OF LEAN CONSTRUCTION

A key vision and goal of the LC Institute is to provide value by achieving both customer and supply chain partner value throughout the project life cycle (LCI, 2016b).Womack and Jones, (1996) stated value as the first principle of lean thinking. In LC, numerous definitions and terminologies of the concept of value have been identified in literature. According to Salvatierra-Garrido, et al., 2012, the LC perspective of value has been strongly influenced by the value generation view of the transformation flow value generation (TFV) model by Koskela. As stated in Koskela, (2000) each of these three concept (TFV) concentrates on certain aspects of production phenomenon: value-adding transformation on Transformation concept; non-value-adding activities on Flow concept; and control of production from the customer point of view on Value generation concept. Ballard and Howell, 1998 also argue that value is created through a process of negotiation between the customer's ends and means.

Additionally, according to Emmitt et al. (2005), value is grouped into internal and external values. While Macomber and Howell, (2004), stated that the basic prerequisite to understanding value is to properly understand waste. Lindfors (2000) advocated that value is the product/service that increases profit, decreases time and cost, improves quality for the company, and generates profit/value for the customer. Wandahl and Bejder (2003) introduced value-based management, which looks at different values to improve effectiveness and efficiency in the construction industry. Emmitt et al. (2004) proposed a three-phase model (value/process/operation) and identified six value parameters. Salvatierra-Garrido and Pasquire (2011) presented the first and last value model (F&LVM), which aims to widely visualise value in the construction sector.

Brimson and Antos (1999) suggested that value depends on the supply chain synchronisation, while Bertelsen and Emmitt (2005) argued that clients represent different interests from three main groups, who value different things at different times throughout the life cycle of construction projects: owner, users, and society. From extensive reviews of literature, Salvatierra-Garrido, et al., 2012 concluded that value is still unclear with various definitions contributing to its understanding with the subjective part of value looking more significant while the delivery of value is more focused at the project level. Emuze and Saurin (2015) asserted that little importance has been given to a constant and internally coherent understanding of value in LC. There have been steady and substantial contributions to the development of value from the LC community through a multitude of relevant aspects.

VALUE IN THE CONTEXT OF VALUE MANAGEMENT

According to Kelly et al. (2015), the concept of value reported in volumes of literature by VM researchers shows a reasonably steady approach to its meaning. The most agreed upon expression is that value is stated in the context of units of function, which may be obtained for a unit of cost, as it is most usually expressed as a ratio of function to cost. The VM practitioners have associated value with user requirements, purpose, perception, and influence. Dell'Isola (1997) presented value as 'the most cost-effective way to reliably accomplish a function that will meet the user's needs, desires, and expectation'. Guiwen et al. (2006) argued that value considers the satisfaction of the user requirements, which are determined by their decisions, expectations, and views for cost paid. The comprehension of value is influenced by a chosen combination of benefits compared with acquisition costs.

Kelly et al (2015) assert that the key weaknesses and difficulties of VM have been acknowledged at the implementation stage of projects and is seen to be declining due to its cost-cutting legacy, one-off intervention predominantly at or around the concept and sketch design stages, with its image creating confusion with other management techniques dealing with value. Over the years, VM have acknowledged other concepts such as benefit realisation, value based thinking style of management etc. However, it can be argued that VM has focused towards the relationship between the user-required functions and cost.

FINDINGS

The principal points of current theory and practice of LC and VM are compared in tables 1 and 2 below. The references for Tables 1 and 2 are listed with numbers. The numbers in the tables refers to these Authors: (Table 1& 2 in Abdelhamid, 2008 [1]; Cell and Arratia, 2003 [2]; Drevland and Lohne, 2015 [3]; Emmitt et al. 2004 [4]; EN, 2000 [5]; Forbes and Ahmed, 2011 [6]; Gui Wen et al. 2006 [7]; Hines et al. 2004 [8]; IGLC, 2016 [9]; IVM, 2015b [10]; Kelly and Male, 1993 [11]; Kelly et al., 2015 [12]; Koskela, 2000 [13]; LCI, 2016a [14]; LCI, 2015 [15]; LLC, 2015 [16]; Leinonen and Huovila, 2000 [17]; Nayak, 2006 [18]; Norton and McElligott, 1995 [19]; Ogunbiyi et al. 2011 [20]; Salvatierra-Garrido et al. 2009 [21]; Salvatierra-Garrido & Pasquire, 2011 [22]; Salvatierra-Garrido, et al. 2012 [23]).

Table 1: Points of Similarity

	Value Management and Lean Construction: shared attributes
Objective	Value creation throughout the whole life cycle. [18], [15]
Origin	1940’s manufacturing – influenced by post-WW2 resource scarcity [12]
Techniques	Each has a set of recognised tools and techniques accredited exclusively to themselves i.e. lean tools, VM tools. But use other tools as appropriate [20][18][6]
Environment and Culture	Collaborative, multi-skilled team environment supported by higher management. Process requires innovation and the involvement of stakeholders in the development of value propositions.[18][12],[6]
Approach	Acknowledge the importance of innovation, benefit realisation, whole life value, asset management, projects, programme & portfolio management, soft & hard value, value-based management, and consider impact on society**. [12] [23]**
Usage/ Application	Applicable in various sectors of the economy beyond manufacturing and construction including government, transportation, business, communication, and services with reports of enhancing other practices. [10] [15]
Mis-use/ Application	Frequently the name is used to describe cost reduction activities and tools used to reduce inputs with a corresponding reduction of outputs [8] [12]
Understanding of Value	Lack a sound theoretical explanation of value but consider it in terms of objective, subjective, use, esteem, cost and exchange [7] [23].[17]
Customer Focus	Understand customer as a combination of commissioners and stakeholders[12][18]

Table 2: Points of Difference

	Value Management	Lean Construction
History	The founding practice was developed by Lawrence D Miles for GE in the USA.[12]	The founding practice was developed by Taiichi Ohno for Toyota in Japan.[6]
Focus	Service oriented and push driven.[12]	Philosophy oriented and pull driven. [6][2]
Structural model	Emphasis on issues on: Value generation [1]	Emphasis on issues on: Transformation of input to output, Flow of work and Value generation [13]
Process	Has a formal standard (BS EN 12973). VM is an extract of the delivery process and commissioned separately to support the project delivery model. It is practiced and operationalized through interventions called value studies at specific phases (value opportunities) and time. It is often used to correct budget overruns [5][12] [21]	No formal standard. LC is a project delivery model in its own right and is chosen rather than commissioned. However, individual tools and techniques are often commissioned separately as project correction interventions. It does not have specific value opportunities, as value is a continuing focus.[6]
Learning	It deliberates on problems and learning is between projects.[12]	It deliberates on process flow, and learning is a continuous improvement within projects across the whole process.[6]
Scope	Manages design and feasibility studies, which improve the value for money of the end product in use (building or structure) through design optioning and redesign in specific workshops. [11] [21]	Manages scope and recognises the delivery process during design and construction. The difference between desired value and realised value is minimised through the elimination of value loss. Considers control and monitoring of value delivery e.g. built in quality, Last Planner® System etc.
Value Delivery	Value achieved through the relationship and balancing of cost, time, and quality. [12][19]	Value achieved by reducing value loss (waste) without a trade-off of time, quality, and cost. [1][14] [17]
Customer Focus	Customer is understood as a series of values and value systems: client's value system, the client's project value system, corporate and business values, project value system, practitioners' value system, consumers' (users'/customers') value systems and stakeholders' value system. [12] [18] [23]	Customer is understood in three ways; External customers paying for (and affected by) services and goods Internal customers receiving services and goods between departments/sections of an organisation Next customer in a process considering the hand over between tasks Customers are recognised as dynamic across the whole life process. [18] [22]
Research	Theoretical development is limited and the view of value and has not really expanded from that developed by Miles i.e. Value is the ratio of function to cost. Other studies	Much research has been carried out to understand value in lean for example the transformation, flow, value generation model; first and last value; value based management; external and internal value; process and product

	surrounding value have concentrated on the relationship between the user-required functions and cost, including value based thinking. [7]	value; value, process, and operation model; the five features of value; and recently the nine tenets of value and so on.[3] [23]
Early Project Stage	VM contributes to a clear customer perspective of value from the early stage of projects. [22]	LC generally acknowledges its lack of addressing the concept of value at the early stage of design. Recent advances include lean design, lean and BIM, integrated project delivery and target value design [4]
Implementation Project Stage	It is reported to be weak at the implementation stage. [12]	Many examples of lean applied within on-site activities exist, the theoretical framework behind lean construction advocates that value is defined in design and lost in the process.[23]
Academic Support/ Body	No academic/theory developing body exists purely to support VM – development is embedded in more general bodies such as CIB, ARCOM etc. The Institute of Value Management (IVM) is largely industry/practice led consequently the knowledge base for VM is practice led.	The International Group for Lean Construction (IGLC) as an academic led body for the development of LC theory to which practitioners make a strong contribution. The IGLC pre-dates the Lean Construction Institute (industry body) and its global satellite organisations. The knowledge base for LC is theory led. [9]
Process Drivers	Value study participants are the primary drivers of value proposals but are not always engaged in the project decision making process. [12]	The people engaged in the process and encouraged to look for ways to enrich the project processes directly. [6] [16]

CONCLUSIONS

This investigation recognises a range of similarities at a high level (Table 1) that could easily point to an early conclusion that LC and VM are interchangeable, leading to the same goal of value delivery. This is most evident in their shared misapplication as cost reduction techniques. However, a more detailed examination indicates significant differences in philosophy and scope in different areas, including project timing, practitioner's duties, areas of practice, and project application. Furthermore, both LC and VM have recognised each other in the past. The ongoing trend of linking VM and lean in topics of discussion for value practitioners is evident at conferences both in the UK (IVM, 2014; LCI UK, 2015) and in the US (SAVE International, 2015a; SAVE International, 2015b). With the institute of value management UK appointing a Lean Construction Group Liaison (IVM, 2015c). Both LC and VM share common origins and methods from the manufacturing sector (IVM, 2015a).

Some known subsets of VM, namely value analysis and VE, have been used in target costing in the manufacturing industry to attain additional cost reductions (Womack et al., 1990). Further, VE and LC have been reported to systematically apply methods to processes/services in order to deliver an enhanced product/service to the customers that fulfils their needs in a timely and cost-effective way with the main aim of maximising value and minimising waste. In addition, LC practices intend to complement rather than compete with VE (Lehman and Reiser, 2004). Also, there have been suggestions of using VM for the practical application of the value generation view on production (Koskela, 2000). LC is a broader philosophy which covers more aspects than value management, it is evident that LC has advanced over the years towards discussions on the concept of value. The current work in LC on value relies less on other construction value-related disciplines such as VM, VE and partnering. Furthermore, LC literature still views value as a confusing concept associated with different interpretations, forming the basis of its understanding.

Although both lean and VM, when applied individually, are beneficial, their combination offers great synergy regarding the concept of value (Cell and Arratia, 2003). The study established that value plays a central role in both LC and VM. Future study should investigate empirically their possible integration towards identifying synergy in the way value is understood and delivered. Which is the next goal of the authors. Moreover, if the view of no single approach being greater in respect to others is accepted, it can be easily established that there may be theories, methodologies, and techniques in each discipline that could support the others (Nayak, 2006). Salvatierra et al. (2008) affirmed that the integration of the concept of value through exploration of VM and lean thinking would add value for delivering satisfactory solutions.

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A FRAMEWORK FOR EVALUATING AN ACTION RESEARCH STUDY ON LEAN DESIGN MANAGEMENT

Sheriz Khan[1] and Patricia Tzortzopoulos[2]

ABSTRACT

There is no convention for evaluating action research (AR), and the one commonly used for evaluating research in general was deemed unsuitable for evaluating a postgraduate AR study on lean design management conducted by the researchers. The purpose of this paper is to present the framework developed by the researchers for evaluating the AR study, using criteria that are different from those traditionally used to evaluate research. It is hoped that this paper will contribute to lean construction research (LC) by highlighting the importance of using AR to measure the efficacy of LC production systems in their intended context of application and by letting future LC researchers know that they can develop their own criteria for evaluating their research rather than use generic criteria that may not be suitable.

KEYWORDS

Action research, LPS WWP, rigor, relevance

INTRODUCTION

Validity, *reliability* and *generalizability* are criteria commonly used to evaluate both quantitative (positivist) research and qualitative (interpretive) research. However, these criteria were developed by quantitative researchers to test the methodological rigor of quantitative research and have been used as the basis for criticizing qualitative research, especially case study research and AR, as lacking rigor and containing bias because of the subjective nature of data collection and analysis employed (Robson, 2002; Yin, 2009). AR has been criticized for its lack of rigor by applying quantitative criteria for rigor: rigor can be compromised if quantitative criteria are applied too rigidly to AR (Dick, 2014). This has raised concerns among qualitative researchers about the practicality of using quantitative criteria to evaluate qualitative research, so much so that there is a growing literature in qualitative research in general and AR in particular that encourages the use of

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criteria other than those used in quantitative research (Dick, 2014). Some qualitative researchers (e.g., Lincoln, 1995; Remenyi et al., 1998; Golafshani, 2003) are content with simply redefining the quantitative criteria for qualitative research, while others (e.g., Miles and Huberman, 1994; Reason and Bradbury, 2008; Coghlan and Brannick, 2010) have proposed different criteria for evaluating AR. The researchers considered the practical relevance of their AR study more important than its methodological rigor so, in the absence of a convention for evaluating AR, they developed their own framework for evaluating the AR study, based on its practical relevance. Before presenting the evaluation framework, AR as adopted in the AR study will be defined, the AR study will be outlined, and a strategy used by the researchers to achieve rigor and minimize bias in the AR study will be discussed.

ACTION RESEARCH

AR is a strategy for implementing and evaluating an existing solution to a practical problem in its organizational context, with the knowledge acquired from the implementation and evaluation used to make recommendations for future application of the solution (Iivari and Venable 2009). It is an approach to research which is based on collaborative problem-solving relationship between researcher(s) and practitioners, which aims at both managing change and creating new knowledge (Coghlan and Davis, 2006). 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 AR but lacking the requisite methodological knowledge to conduct it (Argyris and Schön, 1998; O'Brien, 2001). AR is a flexible cyclical process which allows action (change, improvement) and research (understanding, knowledge) to be achieved at the same time (Dick, 2002). Lewin (1946) is credited with pioneering AR which he portrayed as a spiral of learning steps consisting of planning action, taking action, evaluating action and amending the plan based on what was learned. The iteration within the AR spiral enables action and research to be built up cumulatively: through trial and error, both action and research can be pursued until achieved (Dick, 2014).

THE ACTION RESEARCH STUDY

Using AR the researchers facilitated the implementation of LPS WWP during the design development phase of two building design projects and together with the design practitioners evaluated its effects on planning reliability and workflow variability. The AR study was carried out at two AE firms in Florida. The descriptions of the projects studied are summarized in Table 1. 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 apartment design team consisted of a project manager, the architect, an IA, a structural engineer, an MEP (mechanical-electrical-plumbing) engineer, three EITs, a BIM manager, and five BIM technicians. The design development phase of the hotel project began 6 May 2013 and ended on 23 August 2013; for the apartment project, it began on 8 July and ended on 25 October 2013.

Table 1: Summary of the projects in the AR study

Project	Location	Floors	Size	Construction Cost	Design Phase	Duration
Hotel	Melbourne Beach, FL	7	14,865m²	$23.94 million	Design development	16 weeks
Apartment	Sebastian, FL	6	8,919m²	$13.60 million	Design development	16 weeks

The AR study was divided into two studies: a four-week exploratory study to assess the current design planning practice and design planning reliability, followed by a twelve-week action study aimed at increasing design planning reliability and reducing workflow variability. The exploratory study revealed that top-down, push planning was being practiced in both projects: a design management team, met for an hour or two on Friday mornings, agreed on the design tasks on a master schedule that *should* be performed in the coming week and, without making sure that they *could* be done, *push* them down with instructions and/or sketches to the BIM technicians to create models and generate drawings from them and to the IAs and EITs to research and prepare technical specifications. The IAs, EITs and BIM technicians were left out of the weekly task planning (WTP) process. The average Percent Plan Complete (PPC) over the four-week exploratory study period was 73.1 for the hotel project and 72.3 for the apartment project. This low planning reliability was a cause of high workflow variability.

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). The researchers therefore recommended that the traditional WTP (push planning) be supplemented with LPS WWP (pull planning) during the final twelve weeks of the design development phase. As a result, 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. Tasks were decomposed into smaller, doable assignments. Assignments that should be performed but which were hampered by incomplete prerequisites or unresolved constraints were not scheduled. No assignment was scheduled unless an agreement was reached on who was responsible for timely prerequisite handover and who will perform the assignment and by when. If it was determined that more manpower or other resources would be needed to complete a task on the master schedule by a certain time, then more manpower or other resources would be allocated to that task. PPCs and FRAs (failure reason analyses) played an important role in the LPS WWP implementation and evaluation process.

The AR study took the form of a spiral of steps, signifying the cyclical, iterative and recursive nature of AR (see Figure 1), starting with the four-week exploratory study in which deficiencies in the current design planning practice were identified and remedial actions were planned, followed by the action study in which the researchers and the practitioners engaged in twelve weekly action research cycles of planning, implementing, monitoring and evaluating LPS WWP, aiming to improve each cycle of implementation by applying the lessons learned and avoiding the mistakes made in the previous cycle. The cyclic process was repeated until a sufficient understanding of and actionable solution for the workflow variability problem was achieved. The general goal was to create a simple, practical, repeatable process of iterative learning, evaluation and improvement that would lead to increasingly better results for the practitioners. So, at the heart of each cycle was learning through critical evaluation, i.e., changing patterns of thinking and action that were well established in two groups of practitioners. The idea of the learning cycle is also common to Kolb's (1984) experiential learning cycle and Deming's (1986) quality cycle (Plan-Do-Study-Act or PDSA) which drew upon Shewhart and Deming's (1939) Plan-Do-Check-Act (PDCA) cycle.

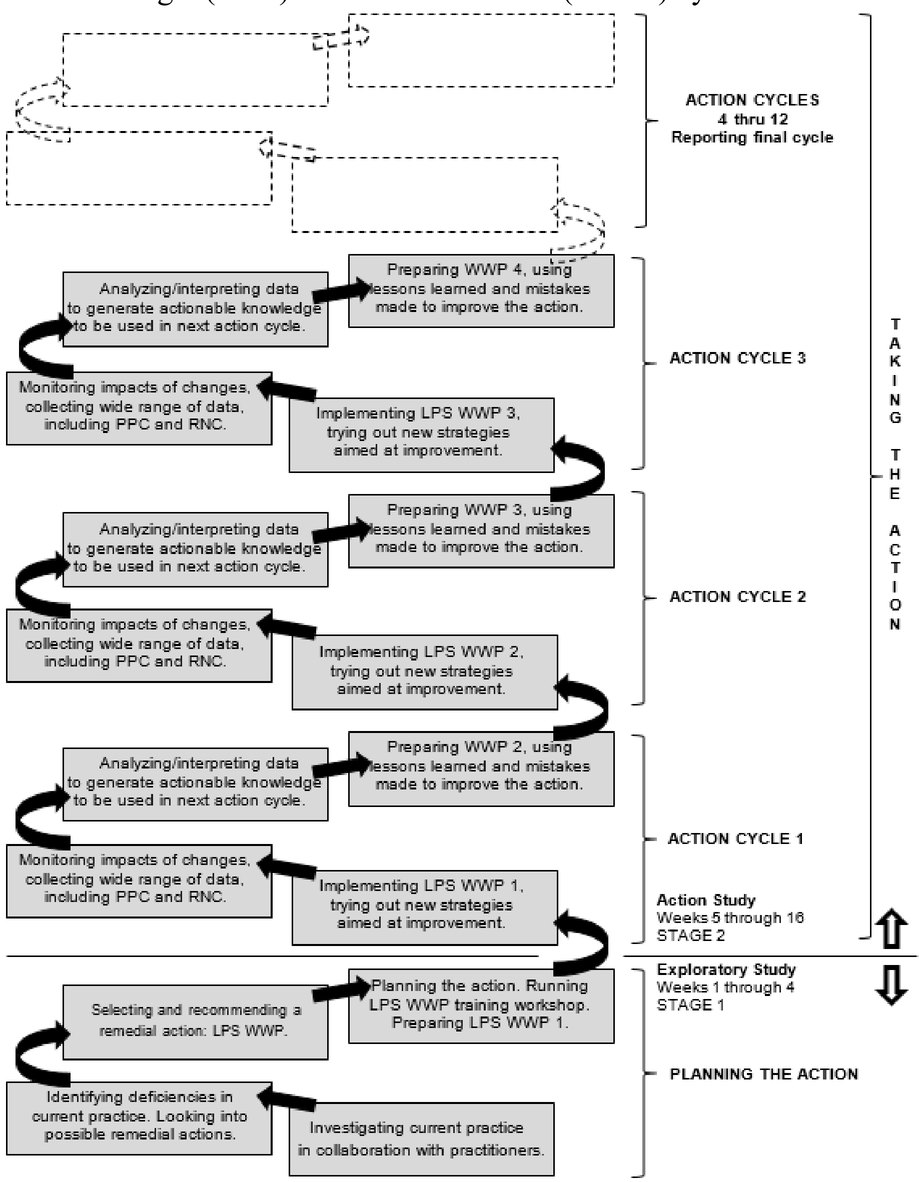

Figure 1: The AR study depicted as a cyclical learning process

PPC Measures Before And After LPS WWP Implementation

PPC measures served as a tangible incentive for the project teams to improve the predictability and reliability of the LPS weekly work plans and provided empirical evidence of the effectiveness of LPS WWP as a design planning and control tool. As shown in Figures 2 and 3, in both design projects, LPS WWP PPCs were higher than traditional WTP PPCs. There was 12% rise in average overall PPCs in the hotel design project and a 14% rise in average overall PPCs in the apartment design project, suggesting that there was an increase in planning reliability and thus reduction in workflow variability during the LPS 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 amounted to a 2.50% and a 3.75% increase in production cost efficiency, respectively, in this phase of the design projects.

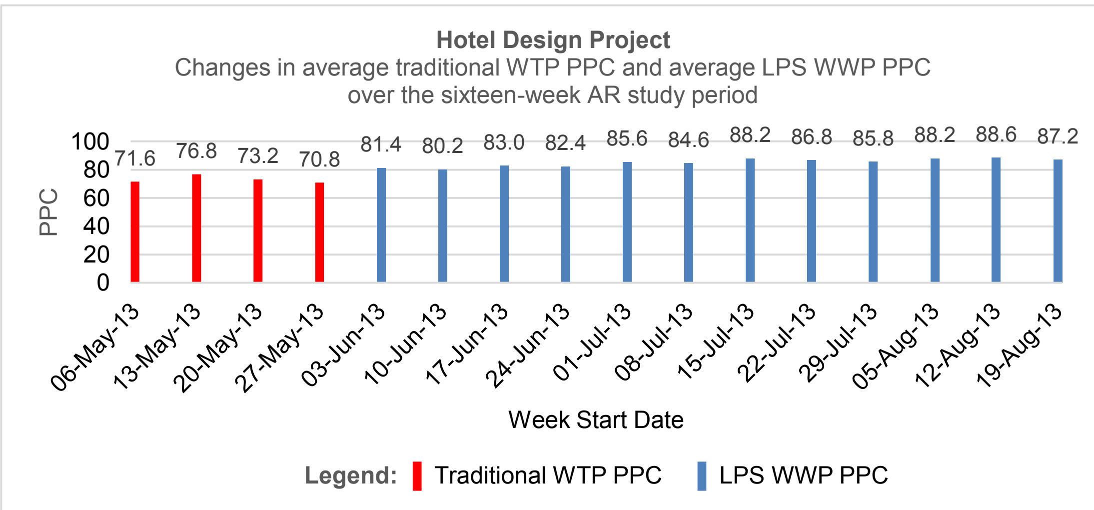

Figure 2: Hotel design project--PPCs before and after implementing LPS WWP

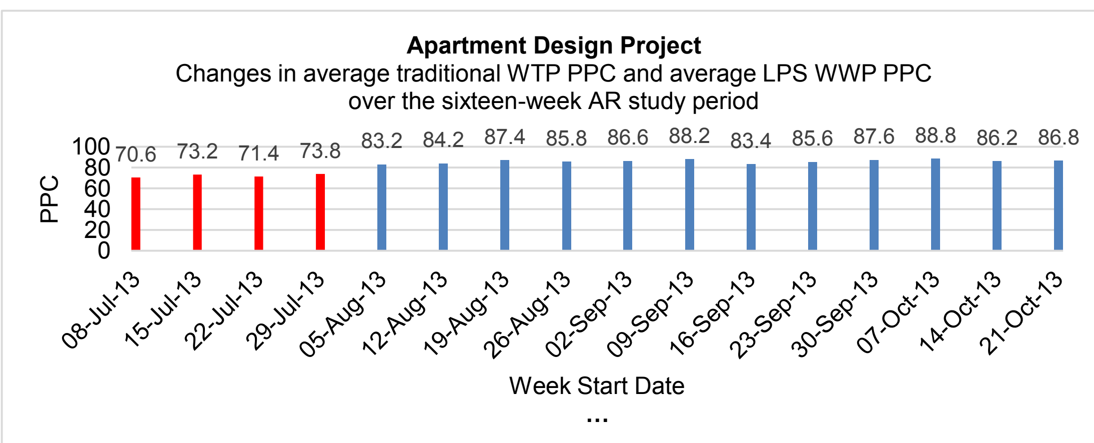

Figure 3: Apartment design project--PPCs before and after implementing LPS WWP

FAILURE REASON ANALYSES

A key feature of the continuous improvement process was the study of the reasons why assignments promised in the weekly work plans to be completed by a certain time were not completed by that time. FRAs were conducted to help improve each weekly cycle of LPS 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 2.

Table 2: 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%

ACHIEVING RIGOR/MINIMIZING BIAS IN THE AR STUDY

Validity, i.e., the accuracy of scientific findings, fit well with quantitative research, but the concept of *validity* is inappropriate for the qualitative part of an action research study, which relies on subjective interpretation of qualitative data collected in complex, uncertain and unpredictable systems (Dick, 2014). When quantitative methods are used in AR, as in the AR study, in which PPC measures were collected and a questionnaire survey was conducted, the quantitative concept of *reliability*—consistency and repeatability of the results over time—can apply to that part of the research, and conventional means of achieving reliability can be used (Dick, 2014). In some forms of AR, reliability and validity are achievable if they are applied less rigidly than traditionally applied (Dick, 2014). Furthermore, it is expected that all good scientific research should in some way or other be generalizable (Dick, 2014). In the strict sense of the term, *generalizability* can apply to the quantitative part of the AR study. However, to the extent that the practitioners in the two design projects and design practitioners elsewhere can use the new understanding of the research problem in similar situations or similar projects, *generalizability* is possible, and a contribution to knowledge can be claimed (Dick, 2014).

The AR study was designed to achieve rigor through data triangulation, i.e., convergence of evidence from different sources (see Figure 4): data was collected from the thirty-three practitioners, using multiple data collection techniques, including participatory and non-participatory observations, semi-structured and follow-up interviews, closed and open-ended questionnaires, individual and group discussions, and document reviews. Rigor was also achieved through methodological triangulation, i.e., convergence of evidence from different methods—quantitative and qualitative, aimed at corroborating the same facts. Methodological triangulation was be achieved through the use of both quantitative and qualitative data collection techniques. Using multiple sources of data and combining methods, as well as multiple projects, strengthened the AR study (Patton, 1990). Active involvement in AR can increase researcher bias; however, triangulation may help to reduce it (Robson 2002). Practitioner participation in the evaluation of the AR study also helped to reduce researcher bias.

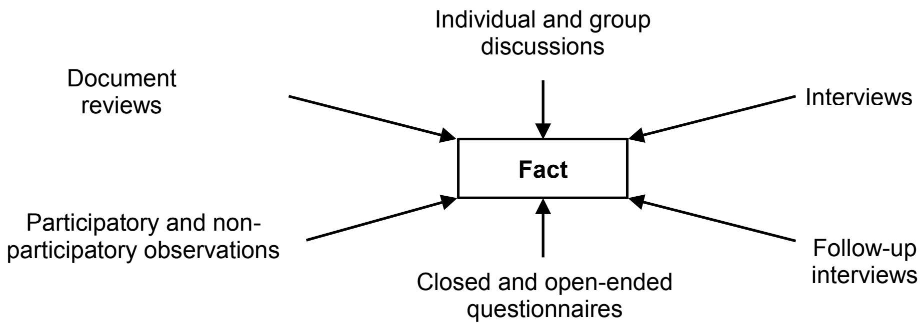

Figure 4: Data triangulation through convergence of multiple sources of evidence

Lastly, the cyclic process of planning, implementing, monitoring and critically evaluating LPS WWP helped the researchers and the practitioners to refine the action strategy as they learned more about their situation. The unfolding nature of the cyclical learning process contributed to the rigor of the research: the early cycles helped the researchers and the practitioners decide how to conduct the later cycles; and, in the later cycles, the interpretations developed in the early cycles were tested and challenged and refined.

THE EVALUATION FRAMEWORK

Continuous, internal evaluation is at the core of AR. As mentioned earlier, the two action studies consisted of a series of informal evaluations of LPS WWP in action. The goal was to continually refine the implementation of LPS WWP in light of the understanding developed in each earlier cycle in order to increase planning reliability and reduce workflow variability.

There is no formal framework for evaluating AR. However, criteria for evaluating AR were found in one or two places in the AR literature. Coghlan and Brannick (2010), for example, proposed following criteria for evaluating AR:

1. Correctness of the original diagnosis
2. Correctness of the action taken
3. Correctness of the way the action was taken

And Reason and Bradbury (2008) proposed what amounts to a checklist for quality in the form of a number of questions an action researcher can ask:

1. Did the research reflect cooperation between the researchers and the design practitioners?
2. Did the research enable actions guided by iterative evaluation as part of the process of change and improvement in the existing practice?
3. Did the research advance your practical and experiential knowledge?
4. Did the research engage in significant work?

5. Did the research result in new and enduring changes?

The criteria proposed by Coghlan and Brannick (2010), the checklist by Reason and Bradbury (2008) and concepts by March and Smith (1995), Kagiolglou et al. (1998), Smith and Morrow (1999), Bresnen and Marshall (2001), Cooper (2001), Tzortzopoulos (2004), and Brady et al. (2013) were used to develop a framework to evaluate the AR study that focused on evaluating its practical relevance. The framework was organized in three hierarchical levels: criteria, attributes and attribute definitions (see Table 3). The attribute definitions and the checklist proposed by Reason and Bradbury (2008) were used to design a questionnaire aimed at obtaining a comprehensive evaluation of the AR study by the researchers and the practitioners.

Table 3: Framework for evaluating usefulness and effectiveness of the actions

Criteria	Attributes	Attribute definitions
Correctness	*Diagnosis*	Accuracy of the original findings
	Treatment	Suitability of the action taken
	Execution	Conformity to the technique used for taking the action
Usefulness	*Applicability*	Appropriateness of the action for the situation
	Practicality	Ease of use of the action in terms of simplicity and clarity
	Flexibility	Adaptability of the action to the current practice
Effectiveness	*Efficacy*	Ability of the action to achieve the intended results
	Measurability	Ability of the action to be quantified
	Acceptability	Ability of the action to inspire trust in its value to practice

THE QUESTIONNAIRE

The questionnaire contained twenty closed questions, which were used to evaluate the correctness, usefulness and effectiveness of both the action and the research, and two open-ended questions, one for the practitioners to compare the design planning practice before and after LPS WWP was implemented and the other to find out what they considered to be the key drivers of and barriers to the adoption of LPS WWP in their firm. The closed questions were set up to be answered using a 1-to-5 Likert response scale, with *Strongly Agree* on one end and *Strongly Disagree* on the other end, and *Neither Agree nor Disagree* in the middle. The closed questions each began with *To what extent do you agree or disagree with the following statement?* followed by a statement (see Table 4).

Table 4: Statements in the questionnaire

1. The researcher's diagnosis of the problems associated with the traditional weekly task planning was accurate.
2. Supplementing traditional weekly task planning with LPS weekly work planning was the right action to take.
3. Traditional weekly task planning was properly supplemented with LPS weekly work planning using action research.
4. LPS weekly work planning was appropriate for the change needed in the design planning practice.
5. In terms of simplicity and clarity, LPS weekly work planning was easy to implement.

6. LPS weekly work planning was adaptable to traditional task weekly planning.
7. Collaborative production planning, task decomposition, make-ready planning, assignment completion commitment, PPC measurements and FRAs analyses introduced by LPS weekly work planning resulted in an increase in planning reliability and thus a reduction in workflow variability.
8. The increase in planning reliability and reduction in workflow variability resulting from supplementing traditional weekly task planning with LPS weekly work planning could be measured accurately.
9. The increase in planning reliability and reduction in workflow variability after traditional weekly task planning was supplemented with LPS weekly work planning has convinced you of the value to design planning practice of supplementing traditional weekly task planning with LPS weekly work planning.
10. LPS weekly work planning provided the workflow control mechanism that traditional weekly task planning lacked and that rendered it inadequate for the complex design project.
11. The action research strategy was correct, useful and effective with regard to allowing the researchers and practitioners to collaborate in systematic investigations, seeking practical solutions to workflow problems.
12. The action research strategy was correct, useful and effective with regard to enabling the researcher to influence practice directly instead of simply being an observer passively collecting data.
13. The action research strategy was correct, useful and effective with regard to encouraging meaningful discussions and hence a better understanding among all concerned of the practices of your firm and the problems in the project that was studied.
14. The action research strategy was correct, useful and effective with regard to permitting the practitioners to contribute effectively, ensuring that all information from target groups and individuals was obtained.
15. The action research strategy was correct, useful and effective with regard to allowing the researcher to diagnose and help solve design planning problems and design workflow problems during the design development phase of the building design project that was studied.
16. The action research strategy was correct, useful and effective with regard to fostering cooperation between the researcher and the practitioners.
17. The action research strategy was correct, useful and effective with regard to encouraging actions to be taken that were guided by iterative evaluation as part of the process of change in the existing design planning practice and improvement in design workflow.
18. The action research strategy was correct, useful and effective with regard to enabling actions that advanced your practical and experiential knowledge.
19. The action research strategy was correct, useful and effective with regard to facilitating the conduct of significant research.
20. The action research strategy was correct, useful and effective with regard to producing new and enduring changes to the design planning practices.

CONCLUSION

Until there is a convention for evaluating AR to follow, lean construction action researchers may have to develop their own set of criteria to evaluate their research.

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VISUAL MANAGEMENT: PRELIMINARY RESULTS OF A SYSTEMATIC LITERATURE REVIEW ON CORE CONCEPTS AND PRINCIPLES

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ABSTRACT

Visual management (VM) is one of the core categories of practices of Lean Production systems, providing the foundation for other improvement approaches to be implemented and, therefore, may be adopted as one of the first steps of a continuous improvement program. However, there are some challenges regarding the implementation of VM in construction sites: these are usually very large and changing environments, teams and equipment are often spread in large areas, etc. The fact that VM practices and tools are very intuitive hinders the explicit presentation on papers of concepts and principles behind this approach. Therefore, a more robust and comprehensive understanding of the term, its concepts and associated principles is necessary. Moreover, there is a gap in knowledge about the understanding of VM in construction from other knowledge areas such as visual languages, design, infrastructure, mechanics of human visual perception, among others. This paper is part of a wider research project and presents preliminary results of a systematic literature review on core concepts and principles of VM. The aim of this study is to contribute to a better understanding of VM, by collecting information from other relevant research areas.

KEYWORDS

Visual Management, Transparency, Systematic Literature Review.

INTRODUCTION

The increase of process transparency, which has been pointed out as one of the core principles of the new production management paradigm, is concerned with making the production process observable in order to facilitate control and improvement (Formoso et

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al. 2002). The same authors define process transparency as the ability of a production process (or its parts) to communicate with people.

Koskela (1992) suggested a set of practical approaches to increase process transparency: (a) reducing the interdependence between production units; (b) using visual devices to enable immediate recognition of process status and deviations from standards; (c) making the process directly observable through appropriate layout and signals; (d) incorporating information into the process at workstations, tools, materials and information systems; (e) keeping a clean and orderly workplace through 5S programs; and (f) rendering invisible attributes visible through measurements.

There is a certain consensus in the literature from the Lean Construction community on the understanding of VM as a way to promote greater transparency of processes and discipline in the production environment (Tezel, Koskela and Tzortzopoulos 2009). Those authors identified seven other functions for VM: promote continuous improvement, facilitate the work, create a sense of shared ownership, support on-the-job training, enable management by facts, provide simplification and unification. However, it is important to consider that the VM can perform many other functions, such as communication and collaboration, as suggested by Nicolini (2007) and Ewenstein and Whyte (2007). In fact, Tezel, Koskela and Tzortzopoulos (2009) argue that a more complete understanding of the term is necessary for a better use of it. Thus,

In another attempt to better understand the VM practices, Tezel et al. (2015) identified fourteen taxonomic elements for VM, proposed in accordance with: the purpose of the devices, application methods and their management goals. They are organized as follows: removing visual barriers, standardization, 5S program, production control, production leveling, quality at workplace, prototyping and sampling, visual signals, work facilitators, improvised VM, performance management by VM, distribution of information through VM, error-proofing systems and prefabrication on site. However, a taxonomy based on practices can become obsolete very quickly because visual tools and practices emerge from new and different needs. For instance, BIM (Building Information Modeling) related visual devices, for example, have not included in that study despite the existing potential for increasing process transparency.

This study aims to contribute to a better understanding of VM through a systematic literature review, by bringing into discussion knowledge from other relevant research areas in which this topic has been investigated. Traditionally, the term Visual Management has been used to describe the visual management practices in the manufacturing and construction industry. However, in the field of information and knowledge management, some similar practices can be found under the terms of information visualization and knowledge visualization (Eppler and Burkhard 2007). In the visual communications and computing field, the term visual languages is often mentioned in academic studies (Zhang 2012, Eppler and Bresciani 2013). Moreover, in the medical field of neuroscience much research has been developed on the mechanism of human visual perception and theories of cognition and perception (Moore 2001). Therefore, a wide range of knowledge areas has been investigating issues related to VM from quite different perspectives.

THE RESEARCH METHOD

According to Petticrew (2001), systematic literature reviews (SLR) are widely used as an aid to evidence based decision making, and consist of a method of locating, appraising, and synthetizing that evidence. It is important to understand that systematic reviews are not just big literature reviews, and their main aim is not simply to be "comprehensive" but to answer a specific question, to reduce bias in the selection and inclusion of studies, to appraise the quality of the studies considered, and to summarise them objectively (Petticrew 2001). The same author also states that, once done, SLR can often identify the need for additional primary studies as they are an efficient method of identifying where research is currently lacking.

The research question that guided the SLR through the databases was: Which are the core concepts or principles of Visual Management? A first run of searches was made in Google Scholar, in order to identify relevant databases. The databases chosen for the searches were: Science Direct, Scopus, Web of Science, ASCE, Emerald, IGLC e Google Scholar. The logical expressions used for primary searches in databases are shown in Figure 1.

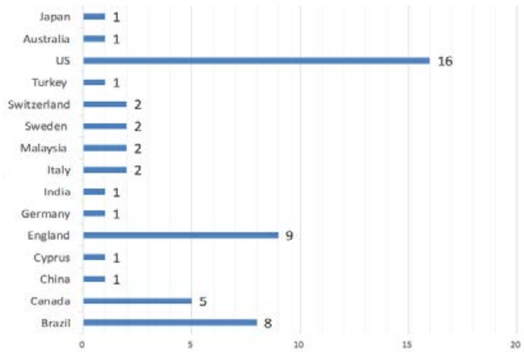
1 - Visual Management	2 - Concepts or Principles	3 - Industry
(Visual AND (Management OR Workplace OR Control OR Factory OR Tools OR Communication))	(Concept* OR Ideas OR Foundations OR Principles OR Elements OR Fundamentals OR Essentials OR Rules OR Tenets)	(Manufacturing OR Construction OR Industry)

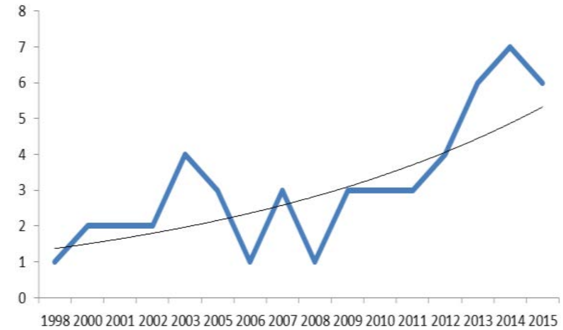
Figure 1: Logical expressions for database searches

Some inclusion and exclusion criteria regarding the title and abstract of papers were used to refine the list of papers selected. For inclusion, the papers had to be English only, theoretical or empirical, define or present a definition of visual management, and focus on sets of tools. Papers containing at least one of the following features were excluded: single tool implementation, forensic and disaster studies, brain research, medical experiments and diseases, geographic information systems or VBA (Visual Basic for Applications) Programming Platform. After this refinement, 60 papers (out of 7,949) were selected for the following phase of the SLR.

For this following phase, some quality criteria were applied to papers: a simple assessment of each paper's background, method, findings use and generalisation was made within a scale of absence (0) to high (3). The papers with the sum below 6 points would be excluded from the list. Also, during the reading of all papers, relevant excerpts of text regarding concepts, principles, benefits, impacts and opportunities for improvement were extracted. After this stage, 53 papers remained in the SLR.

Regarding the origin of papers, more than 60% of them came from the United States, England and Brazil (Figure 2), confirming the known contributions from those countries on the subject for a long time. Regarding the evolution along time, data indicated that visual management has become increasingly recurrent and how the number of publications have increased substantially in the past 15 years (Figure 3).





Figures 2 and 3: Origin of papers and Number of publications per year of analysed papers

One of the most surprising results of the systematic literature review is concerned with the different areas of expertise found. Due to the focus of the systematic review concentrated on management areas, 58% of the articles are within the areas of construction, project management, business and manufacturing. The remaining percentage is distributed by various knowledge fields such as social sciences, neuroscience and visual languages and computing (Figure 4). Such publications, particularly, provided insights for the understanding of visual management in construction from different perspectives.

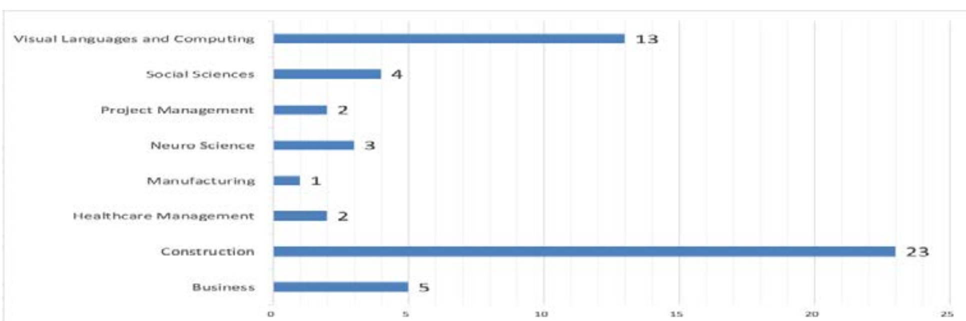


Figure 4: Knowledge fields of analysed papers.

CONTRIBUTIONS FROM THE IGLC COMMUNITY

For IGLC community, the main process transparency definitions are presented by Koskela (1992) and Formoso et al. (2002). Regarding VM definitions most widely used basically are the ones of Greif (1991) and Galsworth (1997). There seem to be a certain confusion in the understanding of the difference between process transparency and VM. Valente and Costa (2014) seek to clarify that process transparency is a principle and VM is a set of practices that have increased transparency as one of its objectives. In fact, Tezel et al. (2013) pointed out that there is no consensus that process transparency is a direct result of VM.

In any case, over the 12 reviewed papers, the authors discuss the relationship of process transparency and other concepts, such as variability (Saurin et al. 2006), management-as-organising (Viana et al. 2014), decision-making decentralization (Bowen and Lawler 1992 apud Tezel et al. 2010), complexity (Viana et al. 2014), rhetoric (Koskela 2015), autonomation (Saurin et al. 2006) and pulled information (Moser and Santos 2003).

Regarding the principles of VM, most IGLC papers are unanimous regarding the use of devices and VM practices that are affordable, portable or mobile, easy to understand and to have information updated, flexible in relation to users' needs, accurate, and financially viable. Other authors also suggest that the VM tools should mitigate system complexity related problems (Viana et al. 2014), contribute for a cultural change in the company (Valente and Costa 2014), be designed for simplicity of functioning (Saurin et al. 2006), match designers and users' mental models (Saurin et al. 2006) and have a behavior-oriented approach for achieving targets (Neto et al. 2014).

In terms of the effects of using VM devices, the readings provided a number of positive impacts: clarify expectations, greater consistency in decision-making, greater participation and motivation of employees, improve the distribution of information (Valente and Costa 2014, Brady et al. 2013), avoid idleness or overload teams, promote collaboration and continuous improvement (Viana et al. 2014, Brady et al. 2013), establish and reinforce a common ground of values and information (Koskela 2015), increase productivity, reduce defects and errors, improve communication, safety and performance in relation to meeting deadlines (Laine et al. 2014).

Tezel et al. 2010 already discussed the importance of information design, information modality and semiotics in the application of VM, which confirms the strong relationship that visual management has with the field of information management. Laine et al. 2014 pointed out that, from an information management perspective, the principles of visual management are difficult to apply to the information flow in digital systems.

CONTRIBUTIONS FROM OTHER RESEARCH AREAS

NEUROSCIENCE

Neuroscience and neuropsychology are concerned with the mechanism of human visual perception and how visual representations stimulate cognition through statistical analyses and different treatments. Spagnol et al. (2015) confirm that illustrations have a more important role in cognitive memory than words and assist in communicating complex messages with simplicity. Regarding the implementation of the steps of the 5S program, for example, that study indicated that 5S visual patterns facilitate the brain pathways for processing information, requiring less new cognitive demands, which can be very useful at construction sites where the majority of employees have low levels of education. By the way, Moore (2001) presented concepts of cognition and visual spatial perception for the communication of concepts of production and construction techniques. That author considers the importance of previous experiences and mental models of users in the desired interpretation of visual information.

Cao and Chen (2014) reported the importance of new discoveries in the visual psychology field for the development of safety facilities in highway traffic. Principles like the effect of persistence of vision and the visual superposition have been used for designing anti-collision equipment and intelligent speed limit signals.

Pavlova et al. (2010) report that not only the visual spatial abilities of navigation and mental rotation are impacted by gender differences, but also that some aspects of social cognition are dependent on this factor. The latest findings indicate that women overperform on visual social cognition tasks, reflecting the dependence of gender in processing of visually acquired social information.

Milner and Goodale (2008) state that visual information is transformed in different ways for different purposes, which suggests a distinction in visual system into vision for perception and vision for action. Those authors also understand that the connection between the two pathways is flexible and indirect, in which cognitive operations like memory and planning play a major role.

SOCIAL SCIENCES AND VISUAL COMMUNICATION

The papers from social and behavioural sciences address the term visual in different ways, emphasising the relationship between visual communication and design and education, culture, society and the formation of skilled and creative professionals.

Dur (2014), in a paper about the reflection of culture in poster design, establishes that visual in “visual culture” can be defined as “everything that is visual, functional, communicational or having aesthetic purpose produced, interpreted or formed by people”. The same author also states that a culture and society’s beliefs, behavioral patterns, values and traditions can influence design processes. In design, establishing effective communication requires the designer to use a visual language that the target audience can understand. In fact, it is important to make effective visual use of cultural codes by first learning, understanding and analyzing the culture of the society in question.

Turgut (2013) highlights the importance of the design and layout of data in a readable, attractive and effective way, in order to support the visual identity of institutions. For this purpose, it is important for all the visual elements of the product to be designed in accordance with the aims of the institutional identity.

Sekeroglu (2012), in an overview of art and design education, understands that visual communication design, which was developed alongside a number of art and design movements and was established upon a contemporary system, has become an indispensable part of mass communication. The author also states that an education system that does not nurture creativity, which essentially constitutes the backbone of the creation process, makes it almost impossible to cultivate individuals who can contribute to the fast changing field of communication design.

Sekeroglu (2012) and Adiloglu (2011) also recognize the different skills professionals of visual communication must develop since childhood and how it is difficult for the society to support the creative thinking for visual communication through educational policies. Moreover, the latter considers visual communication to be an interdisciplinary field. Mange et al. (2015) pointed out the importance of visual environments for the development of visual thinkers.

VISUAL LANGUAGES AND COMPUTING

In the field of visual languages and computing, a fairly different perspective on the subject is adopted. At first, it was concerned with proposing classes, frameworks and methods for conceiving visual languages and representations, in order to promote enough freedom for designing and facilitating the process (Bottoni et al 1998, Costagliola et al. 2002). As this field has rapidly evolved in recent years, the most recent publications address the issue of knowledge visualization, management visualization and collaborative dimensions of visualization (Zhang 2012, Eppler and Bresciani 2013, Yusoff and Salim 2015, Alexander et al. 2015), which can be very useful in the construction industry.

Bottoni et al. (1998), for example, discuss the adoption of dialog controls as a crucial component of visual interactive systems. They argue that a demanding requirement is that it both allows freedom to perform actions according to the user's intentions and yet ensures that only legal actions may be performed, which could be understood as digital poka-yokes. To meet this requirement, they propose a formal method based on the definition of human-computer interaction as generation and interpretation of visual sentences which constitute a visual language. Ahead of its time, that paper described a step in a research program aimed at establishing a user-centered approach to design and implement visual interactive systems.

Costagliola et al. (2002) presented an important step in the design of visual languages: the specification of the graphical objects, and the composition rules for constructing feasible visual sentences. The presence of different typologies of visual languages, each with specific graphical and structural characteristics, yields the need to have models and tools that unify the design steps for different types of visual languages. Thus, when designing a visual language, it can be useful to first analyze its characteristics in order to associate it to an appropriate class. It may be helpful to understand visual management in construction from that perspective, in a way that we must develop models and methods for conceiving and designing new tools, not only try to classify what already exists.

In a more recent paper, Zhang (2012) claims that the discussion of visual communication in management can be considered one of the important topics in the framework of managerial aesthetics, an emerging multi-disciplinary subject which emphasizes the critical roles of visual elements (e.g. in art, design and visualization) in modern management. He also strongly advocates that visual thinking in general and art and design courses in particular should be included in the MBA and executive education curricula.

Eppler and Bresciani (2013), in a response paper to Zhang (2012), highlights how visualization can enhance collaborative activities in organizations beyond cognitive and communicative advantages. That paper reports qualitative visualizations such as conceptual diagrams, metaphors or sketches used as collaboration catalysts to facilitate a variety of tasks, from idea generation to decision-making, planning, knowledge sharing and learning. They also present the notion of collaborative dimensions of visualization: these dimensions can be used to describe the key features of a visual language and determine whether it is suitable for a certain management task or not. They believe that the field of knowledge visualization will establish itself next to information visualization as a separate branch of visualization studies.

Yet around the subject of visualization for collaborative purposes, Yusoff and Salim (2015) define collaborative visualization by the shared use of computer-supported interactive visual representations of data by more than one person with the common goal of contribution to joint information processing activities. They define the use of shared visual representation as how data or knowledge can be captured, represented, presented and analyzed among the users involved.

Lastly, Alexander et al. (2015) recognize the rapid proliferation of visual aids for knowledge work like mind mapping software, screen sharing applications, interactive whiteboards, etc., making visuality to gain a new urgency. In this context, visual restrictiveness, conceived as the constraints imposed by a graphic template on the process of knowledge work, is a highly relevant dimension. The findings of that paper show that visual representations can have a significant impact on the process and outcomes of experience sharing, mediated by the structural pattern of their appropriation.

CONCLUSIONS

The preliminary results of this Systematic Literature Review has indicated that a list of relevant topics related to visual management has been investigated in other research areas. Some of those topics have not yet been addressed neither by the IGLC nor by the Lean Manufacturing community, and deserve special attention. The concern with the visual identity, the social and cultural issues, the association with family mental models and the creative process of developing visual devices should be more emphasised in the construction industry, with the aim of properly implementing in construction projects. It should be possible, for example, from a deeper understanding of these issues, appropriate them to a specific training for the preparation and interpretation of visual devices.

It is also worth noting how visual devices are used for different purposes in contrast with production management. On one hand, the aim of many VM practices in production management is process standardization for rapid detection of deviations. On the other hand, in some social science related fields, the devices aim to stimulate the creativity of users, joint processing of information and collaboration. In fact, they use the terms collaborative visualization and shared visual representations to emphasize the collaborative dimensions of practices.

Finally, it is essential to understand the complex relationship between cognitive process and VM practices. Generally, we associate visual devices to facilitating the cognitive processes of perception, learning and memory, but we do not investigate the inverse relationship. How cognition processes can result in better visual practices? How can we develop better visual devices from a better understanding of human cognitive processes? How can we nurture more visual thinkers in our construction community? These issues deserve further research.

Lastly, some existing knowledge gaps that can be jointly addressed: the absence of a conceptual model that defines information display for strategies without restricting the type of tool to be used, ensuring greater flexibility and the possibility of innovation (as visual languages address); and the need for understanding the visual representations of information as related specifically to each type of user in construction sites, identifying the need to know how to perform their activities as well as why, how and when (in a user-centered approach).

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USING LEAN TO COUNTERACT COMPLEXITY

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ABSTRACT

Based on a literature review and drawing from the experience of lean implementation in multiple construction projects, this paper explores the notion that simplicity and integrality might be crucial for any production system seeking to develop competences against variations derived from both internal and external sources. A discussion using different systems thinking approaches is conducted to provide a better understanding of the volatile behaviour of complex organizations. The aim is to encourage initiatives that address organizational simplicity and integrality in construction projects and, more important, to highlight the important role of lean tools and principles for this endeavour.

KEYWORDS

Systems thinking, organizational complexity, production system design, lean tools.

INTRODUCTION

The challenge of managing complex project organizations points to the importance of shedding light on the reasons why lean tools have been successfully applied in the construction environment while other so-called best practices have not. The current study puts forward that the perceived gains might come from organizational simplicity and integrality supported by lean tools. Simplicity is a desirable feature for a project organizational structure because the low degree of vertical and horizontal differentiation between participants helps to reduce the number of changes and events that cause dynamics (e.g., Baccarini 1996; Ashkenas 2007). Additionally, integrality is based on solutions that enhance organizational proximity in different dimensions and thereby improve interactions between participants (e.g., Voordijk et al 2006).

In order to provide a deeper understanding, the discussion herein revisits the issue of complexity caused by the heterogeneity of project participants and their interaction difficulties. It is initially argued that a clear distinction between the complex and complicated aspects of project production is necessary to understanding the effectiveness of certain tools. With this directive the discussion focuses on nonlinear interactions

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within the project organization because these are the most obviously perceived problems associated with complexity. Variations in productivity rates, rework and other performance measures are herein described as the final results of nonlinear dynamics. Thus, ideas from several system thinking approaches are combined to comprehend how these dynamics originate and propagate within complex project organizations.

Two main guidelines for counter measuring dynamics that cause deviations in performance are identified. Related to system design and operation, these guidelines help to explain the efficacy of the existing lean tools and should contribute to new developments seeking to stabilize production systems. The paper concludes by putting forward the idea that the search for simplicity and integrality, in contrast to complexity, is what intuitively guides the successful renewal solutions in project production.

DISTINGUISHING COMPLEX FROM COMPLICATED

Inside the project organization, nonlinearities cause work efforts to be disproportionate to the results. The nonlinear interactions between project participants are behind what construction researchers (e.g., Koskela 2000; Ballard et al. 2001) call the variability of systems and subsystems. This means that variations in performance measures are the final result of nonlinear dynamics between participants. Therefore, regardless of having been started by an external or internal event, the dynamics are aggravated by flaws in the interconnections within the organizational structure.

This notion leads to a review of the common understanding of project complexity. To begin with, Snowden (2003) defines products (engine, refrigerator, car, house, etc.) as complicated systems, since their components are stable with time and can be improved by optimization. In this case the whole is equal to the sum of its parts. Differently, complex systems are complicated and unstable, which means they change shape and pattern with time (e.g., Ottosson and Björk 2004). A business organization is a good example of a complex system where small changes expressed through management decisions are amplified by other actors and disproportionately cause large effects. The more people involved the more probable it is that completely uncontrolled dynamic changes will occur. The nonlinear interactions among them make the whole differ from the sum of the parts.

For a long time, the common assumption was to interpret projects solely as complicated systems, as demonstrated by the use of transformation model concepts and tools like PERT/CPM and Line of Balance (e.g., Mendes Jr. and Heineck 1999). Afterwards there was a tendency to interpret projects exclusively as complex systems (e.g., Bertelsen 2003; Bertelsen and Koskela, 2003). However, both approaches need to be reconsidered and combined so as to visualize each project as a blend of complicated system (product) and complex system (organization). The two realms must be dealt with in different but complementary ways (e.g., Figure 1).

A product is characterized by a set of attributes like purpose, criteria, functionalities, components and value. These attributes establish the product’s cost, quality standards and degree of constructability. Changes in attributes affect how simple or complicated will be a product. On the other hand, an organization is characterized by the policies, processes, strategic choices, resources, capabilities and competences that generate its robustness and constraints. Changes in these characteristics alter the system's robustness and transform the way the various subsystems interact routinely or when submitted to sporadic events.

There is no direct relationship between the product's level of complication and organizational complexity. A complicated product can be entirely designed and built by a small team if there is sufficient time and skills. This corroborates the notion that organizational complexity is not just a consequence of product type, but rather the cumulative result of decisions regarding business selection, structure and management (e.g. Gröbler et al. 2006; Ashkenas 2007). Therefore, a small project can be more complex than a large one if there is a great amount of uncertainty, either in product goals or in organizational methods, added to time and cost constraints (e.g., Williams 2002).

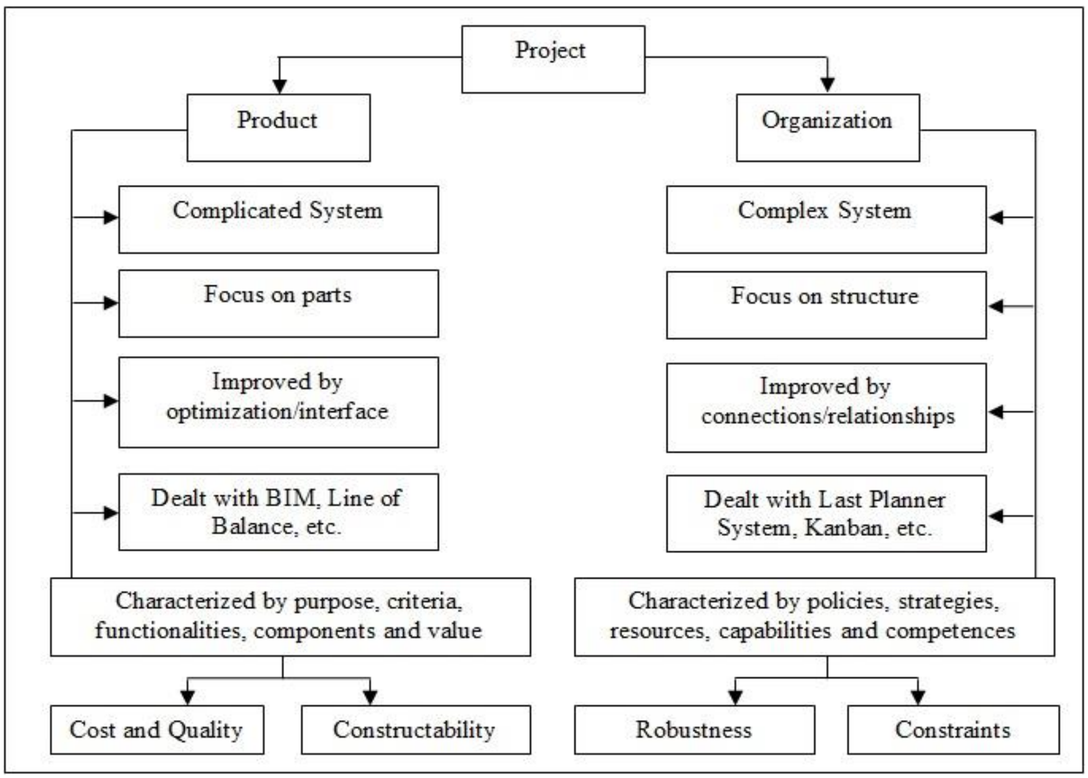

Figure 1: A Model for Project Realms, where Complexity is more Directly Derived from Organizational Characteristics and not Necessarily from Product Attributes

Distinguishing a complicated system from a complex system is an important step to guide improvements in project performance. As mentioned by Sargut and McGrath (2012), serious, expensive mistakes are made when a complex organization is managed as if it were just a complicated one. Ottosson and Björk (2004) observe that traditional management practices can deal well with complicated systems, i.e. systems consisting of many components that are stable over time. Complex systems, on the other hand, cannot be dealt with in the same way as stable systems, because the changes are greater in each chosen time interval. The nonlinear interactions in complex systems cannot be predicted by traditional budget and schedule tools, as they are the results of relationships inside and among the various subgroups in the structure. Thus, countering the harmful effects of nonlinear interactions requires paying close attention to the design of functional areas in the organization structure and managing work efforts in real time as much as possible.

UNDERSTANDING NONLINEARITIES AND VARIATIONS

Understanding nonlinear dynamics and how they are aggravated is a prerequisite to devising solutions for structuring and managing large project organizations. When facing a problem, managers tend to assume that some external event caused it. But not every problem is caused by an external event and secondly, the way external events evolve and are dealt with pretty much depends on the organization's internal capabilities. From the viewpoint of systems thinking, the internal structure is often more important than external events in generating problems that affect performance (e.g., Kirkwood 1998).

The problems faced over and over by the management team are, very often, symptoms of an underlying cause in the organizational structure. Focusing on a symptom leads to corrective interventions that may amplify the problem or even generate other deviations. For this reason, Toyota's strategy says "ask why 5 times", which is its way of pointing out the need to find the underlying cause. However, perceiving how nonlinear dynamics originate and propagate requires combining ideas from different systems thinking approaches like theory of constraints, system dynamics and complexity theory.

To begin with, Kirkwood (1998) states that many business processes are nonlinear, especially when pressed to extremes. For example, while it may be true that if an employee works ten percent longer hours he will accomplish ten percent more work, it is probably not true that if he works twice as many hours he will accomplish twice as much work. By trying to increase even further the amount of overtime the employee soon suffers from fatigue, which leads to a reduction in his working effectiveness. Similarly, despite the efforts of the sales team, if the degree of customer demand grows too rapidly the available production capacity of a manufacturing plant may limit the amount of a product that can be sold, making customer satisfaction give way to dissatisfaction. These are both practical examples of nonlinear responses encountered by business organizations. In both cases the final result is quite different from what was originally intended.

What stands out from these examples is that the nonlinear behaviour of the interactions is aggravated by constraints in the systems. Different constraints have in common the fact that they are related to the capacity of the resources involved. Indeed, resources are defined as things that have a limited capacity to bear strain; e.g., labor, tools, equipment, space, and time (e.g., Ballard et al. 2001; Ballard and Howell 2003). Although systems are sometimes constrained by policies (e.g., Goldratt 1990), it is a fact that rules can be stretched while resources are often physical entities that cannot. This shows the need to consider the impact of overloaded resources in cause-effect chains.

Regardless of having been started by an intended or unintended event, the dynamics originated after exceeding a resource's load capacity will always be harmful to business performance. As a matter of fact, if the desired state of a subsystem is characterized by specific values for a relevant set of variables, an event causing one of those variables to change beyond a tolerable limit alters the state and is, thereby, considered to be disturbing the course of the subsystem (e.g., Campagne et al. 1995). For this reason, Van der Merwer (2002) mentions that often the optimal operating point of a subsystem is near the limits of constraints in the operating window.

However, in construction projects the currently impeding constraint typically changes with time and situations. Therefore, there may be little time to identify and exploit internal constraints in complex adaptive systems that have a continuously changing structure (e.g., Meijer, 1998). To make matters worse, the hierarchic layers and different occupational specializations within the organizational structure added to the peculiarities of site production have a negative effect on the degree of operational interaction between project elements. This implies that there can be not one, but many unknown constraints that are being pushed to the limit as the dynamics propagate throughout the organization all the way to the frontline workers. Consequently, what may seem like a simple decision or request to a project stakeholder can turn into a major exercise for hundreds of other people. Connection problems between components of a large system and the lack of sufficient information regarding the existing constraints explain why a series of outputs may appear random to an outside observer.

The notion that dynamics of both intended and unintended events can cause positive and negative influences shows that it is paradoxical that a construction project is itself a process of continuous change, but within the project every change may be hazardous (e.g., Love et al. 2002). In construction, managerial interventions to cope with environmental dynamics or to initiate planned activities start dynamics that rapidly create intermediate states or move the production system from one project phase to another (e.g., Bertelsen 2003). Alterations in product specifications or scope, handoffs between specialists, increases in the workforce, and changes in the construction site layout are just a few examples of such events.

Knowing that dynamics causing positive and negative influences co-exist throughout a project's life cycle implies that appropriate solutions need to be devised to maximize the positive effects and minimize the negative ones. Although a source of managerial concern, this volatile systemic behavior can be prevented if addressed early in the process of production strategy formulation. The decisions made when designing the production system can not only create capabilities that reduce the negative influences of harmful dynamics, but also induce a project to undergo less intersecting phase transitions. Underlying the production system design and operation should be the philosophy that a system cannot achieve management goals nor be improved if it is not stable. Even though construction projects need to pass through a series of phase transitions, it is necessary to place emphasis in understanding how production systems can be designed and operated to deal with dynamics that cause a process to vary from the expected or desired state.

PROPOSING GUIDELINES FOR STABILIZATION

Field observations support the notion that overloaded resources in cause-effect chains aggravate the nonlinear behaviour of interactions. Another interesting notion is that nonlinearities between project stakeholders naturally arise from their distance in terms of communication, geography, work pattern, culture, and technology. Those two insights are particularly important to appreciate the difficulty of making decisions in a temporary organization characterized by high division of work and many hierarchic layers.

Even so, decision-making in construction management is mainly based on the reductionist thinking, where the focus is on a smaller number of decision areas and possible outcomes. This is especially true for time-stressed situations. Reductionist thinking causes managerial interventions to be more frequent and commonly taken from a macroscopic perspective. A large project observed macroscopically is characterized and evaluated based on few variables, which creates the illusion of a predictable behaviour. Hence, decisions are made considering a relatively small number of variables, such as the match between resources and tasks to accomplish a project schedule. However, as mentioned by Ottosson and Björk (2004), decision-making centralized in upper hierarchic levels will have serious problems in grasping the small things, which include interrelationships and constraints. Thus, in a particular project the different interventions are either done: optimistically, with unknown constraints being overloaded and starting harmful dynamics; or pessimistically, with unknown constraints being dealt with by buffers placed in project plans. This provides a partial explanation to why detailed long-term planning and budgeting are rather meaningless in practice.

The combination between reductionist thinking and macroscopic perspective illustrates the problem with strategies that allow the occurrence of many events and that foster centralized decision-making. The high probability of occurring uncontrollable dynamics that cause deviations indicates that managers should not try to manage complexity, but rather to organize their way around it (e.g., Meijer 1998). Therefore, two complementary guidelines for a better stabilization of large project production systems are proposed:

Reduce the number of intended and unintended events/changes to be handled by the production system. This first guideline is more related to organizational simplicity. Intense and overlapping managerial interventions to absorb environmental dynamics or to initiate planned activities are likely to overload resources and thereby start harmful dynamics. For this reason, over-intervention, which is quantified by the magnitude and the frequency of changes, is counter-productive.

Improve the production system's integration by increasing the quality and quantity of interactions between project stakeholders. This second guideline is more related to organizational integrality. Designing a production system in a way that enhances the degree of proximity between participants improves their interactions and allows them to help in keeping the subsystems operating optimally near the limits of the closest active constraints. This reduces nonlinearities in the system and consequently enhances project performance.

FOLLOWING THE GUIDELINES THROUGH LEAN

In order to follow the guidelines, it is important to perceive the drivers of organizational complexity that can be minimized. The first influence comes from external drivers of complexity. The business strategy establishes the external environmental complexity in which the firm will compete. As a result, the complexity of the organization's internal structure tends to match that of the external environment. Even firms that have outsourced many of their production tasks still need to take into account a number of aspects and to emphasize control on the interrelations with the outsourcees (e.g., Meijer, 2002). This is especially true for the lead firm in a large-scale product development characterized by site production and performed under a tight schedule.

Fortunately, business organizations are able to select to a certain degree the external environment they want to live in depending on its complexity (e.g. Gröbler et al. 2006). It is up to top managers to decide about a specific strategic orientation or particular geographic area in which the firm will compete. Therefore, complexity is considered lower for firms with a focus on certain customer segments or higher degree of geographical concentration. The choice to create value for a limited well-chosen set of customers helps to reduce the number of aspects that need to be taken into account simultaneously and to lower the bandwidth and randomness of interrelations (Meijer, 2002). In other words, focusing the business proposition can not only reduce the exposure to events and unplanned changes that cause dynamics but also improve the quality of interactions between stakeholders. This is well aligned with the abovementioned two guidelines for improving systemic stability.

Regarding the second influence to organizational complexity, it is important to recognize the internal drivers that largely contribute to the heterogeneity of participants, functions, and processes performed within the system. As mentioned before, the way an organization is structured strongly shapes its inner complexity. Therefore, despite the influence of contextual factors in the external environment, at least to a certain degree, organizations are able to reduce internal complexity (e.g. Gröbler et al. 2006).

The reduction of internal complexity is justified by the need to counter nonlinearities. The notion that both intended and unintended events can start harmful dynamics highlights the importance of organizational features that shield downstream activities from disturbances or that foster adaptive management schemes (e.g., Mawby and Stupples 2002; Ballard and Howell 2003). To do so, organizational structuring in civil construction should pay more attention to strategies and practices that enhance simplicity and integrality. Organizational simplicity based on low differentiation can reduce changes and events that cause dynamics. Complementarily, organizational integrality based on proximity in different dimensions can reduce nonlinearities within dynamics.

Initiatives aimed to strengthen linkages between participants in temporary organizations allow them to help in keeping the dynamics from over loading the currently active constraints. The lower degree of differentiation and the higher degree of proximity eliminate intermediate barriers to flows, including layers of authority relationships in the chain of command, and empower people at each level to make decisions and solve everyday problems. Hence, each work team becomes an attractor that ensures that a subsystem will move to the desired state during a phase transition or that it will remain stable when disturbances occur. A production system founded on lean principles and tools seeks to create the same systemic behaviour, but with the purpose of using it to increase the stability needed to achieve management goals. Table 1 provides examples of tools that are advocated by lean practitioners and that seem to be well aligned with the two guidelines for systemic stability.

Table 1: Examples of Tools that Follow the Guidelines

Lean Tool	**Reduce Intended and Unintended Events/Changes (more related to simplicity)**	**Improve the Quality and Quantity of Interactions (more related to integrality)**
Design-Build	Generates fewer handoffs and reduces problems during the construction phase	Enhances data management and exchange between specialists
Partnering	Reduces uncertainties like supply shortages and utilization of work capacity	Creates common work methods, knowledge and values
Relational Contracting	Avoids disputes by establishing the framework in which interactions will occur	Establishes common business mores, benefits and burdens
Last Planner System	Influences factors upstream through medium and short term planning	Improves commitment to goals and cooperation in finding solutions
Mobile Cells	Generate fewer handoffs and rework interventions	Connect workers and tasks in terms of time, space and information
Andon	Helps in preventing disturbances in ongoing operations	Improves communication of work status between teams
Kanban	Reduces inflow variations and avoids overloading the systems with work in process	Enhances lateral relations between specialist and support teams
5S	Avoids careless handling and storing of materials that can lead to supply shortages	Improves transparency and flows between workstations
Visual Control Methods	Clarify what is and what is not being done so as to avoid interruptions in the workflow	Connect teams with timely information for many forms of actions
First Run Study	Allows an early identification of constraints that could affect the work	Allows a better adjustment between product and work methods

CONCLUSIONS

Project management is commonly described as a mature topic. However, the layers of complexity that have been added to construction projects have placed project managers too far from where value is being created to the final customer. Thus, even though projects are temporary processes, construction managers should not be seen as process leaders because of their macroscopic perspective of what is going on. Their frequent interventions may exacerbate complexity or cause deviations. Instead, process leaders should be the people who are actually closer to the operations. This insight shows the need to change managerial schemes and habits, because organizational complexity is a cumulative by-product of decisions regarding business selection, structure and management. Therefore, complexity leads to revaluating traditional paradigms about system design and operation in construction projects.

In a large-scale product development, an effective effort to create stability during the project's short life cycle requires managerial actions by people at all levels of the temporary organization. However, the proactive behaviour of all participants is very much dependent on structural arrangements made by the general contractor. One necessary arrangement is simplicity in terms of less division of work and hierarchical levels. Another important arrangement is integrality in terms of geography, work pattern, culture, communication and technology. Despite influence coming from external drivers of complexity, internal arrangements that foster a lower vertical and horizontal differentiation and a higher proximity in different dimensions can reduce to a certain degree organizational complexity. As a result, different stakeholders, including frontline workers, become empowered to reduce the number of events handled by the production system and to help in keeping it operating optimally against production constraints. This reduces nonlinearities in the system and consequently enhances project performance.

Although the TFV model has been the major foundation for developments in lean construction, the systems thinking approach can also help in understanding what works and what does not in a construction environment. The strategic nature of lean implementation points to the importance of using systems thinking, since stability is affected by the design and operation of an organization and its functional areas. The discussions herein indicate that future studies in lean construction should address organizational simplicity and integrality because both concepts seem to be intuitively guiding the successful renewal solutions in project production. Further research is needed to expand the comprehension of their role in the issue of systemic stability.

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APPROACH FOR BIM IMPLEMENTATION: A VISION FOR THE BUILDING INDUSTRY

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ABSTRACT

Building Information Modeling (BIM) has been widely studied in recent years. Most of these studies are dedicated to understanding the application of BIM to solve specific problems (e.g. clash detection and 4D simulation). Other studies are related to BIM implementation manuals to help companies with this process, considering different stakeholder perspectives (owners, contractors, subcontractors, architects, engineers and suppliers). Some previous studies concentrate on the technical and operational aspects of BIM while others focus on diagnosis of current BIM implementation worldwide. However, there is a lack of studies about strategic vision for the implementation of BIM when considering the construction industry. Therefore, the aim of this paper is to identify key issues related to strategic aspects of BIM in the building industry, focusing on political, procedural and technological facets, using the practical knowledge of lean implementation.

KEYWORDS

BIM, Lean Construction, Strategic Planning, Strategic Alignment.

INTRODUCTION

In general, the implementation of Building Information Modeling (BIM) has been slow and is concentrated in only a few companies. Such projects are developed internally without the in depth participation of designers (architects and engineers). Many of these projects adapt CAD designs to 3D designs, using software related to the BIM platform (e.g. Revit), and technological resources for things like clash detection and quantity take off, emphasizing technical knowledge.

Previous studies (CIC 2011; FIATECH 2013; Jung and Joo 2011) present implementation manuals or guides that show a detailed step-by-step methodology to help companies work with BIM in the future. In turn, Eastman *et al*. (2008) discusses the BIM implementation process, considering the different visions, issues, and needs of owners, general contractors, contractors, designers and suppliers.

Bernstein *et al*. (2013) presents a study about the maturity of BIM in different countries, considering aspects such as: client satisfaction, financial investment and the technological information level. Additionally, potential improvements for each country

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are discussed. Smith (2014) explains the implementation processes within different countries, concluding that public empowerment has an imperative role in this process.

In addition, Succar (2009) presents a framework for the BIM implementation process, divided into three aspects: policy (rules and patterns), process (phases for implementation, based on time and cost) and technology (infrastructure to support the implementation process). Moreover, Succar (2009) proposes stages of BIM application (Pre-BIM, Modeling, Collaboration and Integration). At the end of these stages, the company would obtain the Integrated Project Delivery (IPD) level. In another paper, Lindblad and Vass (2015) highlight the importance of owner mindset for the success of organizational change.

Furthermore, the use of BIM must involve a wider approach, due to the increase in the complexity of projects and the potential of BIM to support improvements in the design, construction, operation and maintenance of building projects. Hence, these improvements increase productivity. For this reason, companies need to understand that BIM has a close relationship with productivity.

Moreover, there is a high appreciation of the operational vision, emphasizing aspects like worker skills to use software related to BIM, but not a deep or extensive use of BIM's modeling aspect. This process needs time and resources to prepare people, define rules and patterns and obtain infrastructure (software and hardware). Because of this, it is important to have discussions about strategic approach (long term vision), when considering BIM implementation with an innovative process, and all building stakeholders related to industry (contractors, designers and suppliers), government (national, regional and local) and academy (technical labor schools, colleges and universities) need to be involved.

In some countries, the BIM implementation process is just beginning. Only a few building companies and design offices (mainly architectural) are using it regularly. Many companies are waiting for the results from these first steps before deciding to invest in this new reality. This is a reactive approach, like most organizational change processes. It's also important to note that the public sector has not taken the first steps towards using BIM in public projects yet. Academia, in turn, is beginning the process to include BIM methodologies in curricula, particularly in architectural courses.

These discussions have shown little emphasis on the strategic vision of the implementation process of BIM in the building industry. Consequently, a research question is presented: How can we increase the strategic vision of the implementation process of BIM in the building industry? The aim then of this paper is to discuss guidelines for increasing the strategic approach in the implementation process of BIM, considering its relationship to lean philosophies, because both lean and BIM are directed towards waste reduction, rework reduction and increased productivity (Sacks et al. 2010a). Lean construction has been implemented since the 1980's and its background could very well help the implementation process of BIM.

BACKGROUND

BIM implementation can be divided into project based, organizational based and industry based processes. Additionally, there is an organizational change process, linked to a strategic fit and innovation process. These three phases can be presented as concentric circles (Fig. 1), showing that the industry level depends on both organizational and project levels.

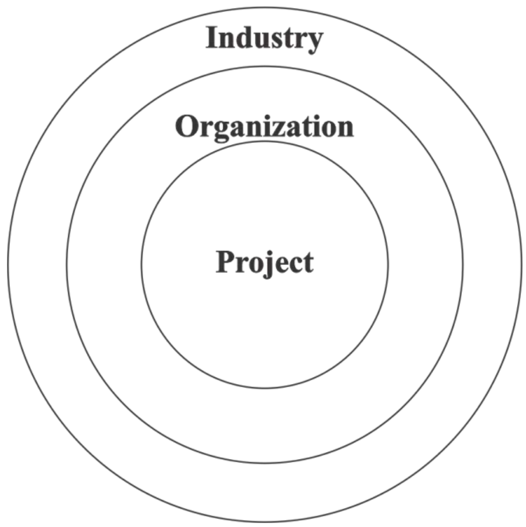

Figure 1: Different levels of implementation of BIM (e Lean)

PROJECT-BASED BIM IMPLEMENTATION

Many studies discuss guidelines for the implementation process of BIM in specific projects. CIC (2011) presents procedures for the planning and execution of a project by applying the BIM platform. In this, four points are discussed: identification of the aims and usage of BIM; mapping of the BIM implementation process within the specific project; definition of the information exchange process among stakeholders; and a definition of the infrastructure that supports the implementation process of BIM. On top of this, there is a discussion related to organizational questions that would influence the implementation process: definition of a mission for the project; definition of a leader for the implementation process; partner commitment; direct involvement of the project leader; discussion about the collaborative process; and appreciation of team work. This publication is one of the most important references for the implementation process of BIM in specific projects.

FIATECH (2013), in turn, presents a comparative study among some examples of the implementation guide of BIM. 28 proposals are shown (eight related to third party institutions and 20, for private and public institutions, including governmental agencies and universities). 22 proposals were developed by American institutions, and the remaining six were developed by Norway, Hong Kong, Finland, Australia, Singapore and the United Kingdom). All of them present means and procedures of the implementation process of BIM in specific projects, with a strong operational approach.

Jung and Joo (2011) also present a framework to help in the implementation process of BIM in specific projects which concentrates within three dimensions: technology (T), perspective (P) and business (B). Each one is divided into categories: T (data property, the relationship between data, data patterns and data use); P (industry, organization and project); and N (planning, R&D etc).

Gu and London (2010) present four fundamental steps to support the implementation process of BIM: definition of scope, purposes, roles, collaboration and phases of the project; development of task processes; identification of technical requirements; customization of process and evaluation of skills, knowledge and capacities of people. These authors reinforce the importance of people to the implementation process of BIM, according to Khosrowshahi and Arayici (2012).

Finally, Eastman *et al*. (2008) introduce guidelines for the implementation process of BIM, considering the different visions of stakeholders (owner, contractor, subcontractors, engineers, architects and suppliers). They discuss the BIM process from each point of view, emphasizing the technical aspects of the implementation process for each stakeholder and their peculiarities.

ORGANIZATIONAL-BASED BIM IMPLEMENTATION

NIBS (2007) discusses patterns, politics and rules related to BIM, aiming to give orientations in the implementation process of BIM for American companies. He states, project stakeholders should use the same language, thus improving the use of BIM. To do this, it is necessary to solve the problem of the information exchange between different kinds of designs. The solution is the development of Industry Foundation Classes (IFC), a conceptual data schema and an exchange file format for BIM data (ISO 16739:2013) that enables a solid data exchange between different languages and software. For example, national standards are discussed to help companies in the process of exchanging information, as well as rules and orientations related to security and information storage. Finally, NIBS (2007) is interesting because it presents guidelines to support the long-term use of BIM in organizations.

Succar (2009) presents three fields for implementation of BIM: Policy, related to regulations, building standards, contractual agreements and benchmarks; Process, related to the stages of model creation, drawing up documents and components, considering time and cost; and technology, definitions about BIM software, communication systems, equipment and peripherals, database technologies and model servers to support the implementation process of BIM. In sequence, he divides these fields into steps, indicating the required decisions for each step. For technology, the steps are software, hardware and network, while for process they are leadership, infrastructure, human resources and products & services. For policy, steps are contractual, regulatory and preparatory. An adequate interaction of these fields enables a successful implementation of BIM. The author presents maturity stages of BIM implementation: Pre-BIM, Modeling (based on object development), Collaboration (based on collaborative works among stakeholders), and Integration (based on net integrated works among stakeholders). In the end of this process, companies will be working in an IPD approach, when all three fields are strong and BIM is being used across the board.

For Miettinen and Paavola (2014), a great challenge for companies is to consider the implementation of BIM as an organizational change process that must make an impact on management and contractual processes. At this moment, a strong resistance to change will come up in most companies, mainly in the building industry. Miettinen and Paavola (2014), also advocate BIM as a strategic resource that impacts different areas in companies and, consequently, leaders need to change their minds about this. Moreover, they must have an integrated vision about the implementation process of BIM that has been emphasized as a collaborative process among all areas of companies, creating a knowledge generation process. Government also has an important role in this process because it could define aims and deadlines to use BIM in society. Governments could also incentivize the use of BIM in construction of public buildings, therefore creating a BIM culture. Aranda-Mena et al. (2009) and Khosrowshahi and Arayici (2012) reinforce this discussion, claiming fragmentation and calcified processes inhibit widespread change in the building industry. For them, technology alone cannot support the implementation process of BIM in the long term. The business process models need to change. And so, the implementation process of BIM is directly related to an organizational change.

Succar and Kassem (2015) argue that BIM implementation refers to the set of activities undertaken by an organizational unit to prepare for, deploy or improve its BIM deliverables (products) and their related workflows (processes). For them, BIM capability is achieved through well-defined revolutionary stages (object-based modeling, model-based collaboration, and network-based integration) separated by numerous evolutionary steps. As well as this, BIM maturity (or post-implementation) is the gradual and continual improvement in quality, repeatability and predictability within available capabilities. Then, there are five maturity levels: [a] Ad-hoc or low maturity; [b] Defined or medium–low maturity; [c] Managed or medium maturity; [d] Integrated or medium–high maturity; and [e] Optimized or high maturity. Companies change their maturity stages with considerable investment in human and physical resources. Each new stage needs new organizational abilities and deliverables not available in previous stages. Each stage requires its own readiness ramp, capability jump, maturity climb, and point of adoption.

INDUSTRY-BASED BIM IMPLEMENTATION

A study developed by McGraw-Hill (2014) presents an overview of the use of BIM in different countries (the United States, Brazil, South Korea, Japan, Australia and New Zealand), analyzing different metrics (e.g. Contractor's perception of BIM proficiency, Impact of BIM expertise on team formation, BIM benefits, Contractor's current perception of ROI, BIM investments etc.). There are some discrepancies among countries. The United States are at a superior level in relation to Brazil and Australia/New Zealand, but the use of BIM is increasing in these countries more than any others. An important point when looking at Brazil and some other countries, is a lack of clear leadership of the coordination of the implementation process of BIM linked to government, as we see in Finland (Smith 2014).

Murphy (2014) considers the implementation of BIM as an innovation process (product and process). Besides this, he emphasize that one of the most important problems of BIM implementation is a short term vision of those responsible for the process, because they do not consider the big picture. This includes some stakeholders and their several competencies (information and communication, cost management, human resource management, technical expertise, time management, strategy and political, culture and values) to be developed according to the objective of each one. Coordination and collaboration among stakeholders is fundamental for the success of the implementation process. Hence, the main problems of implementation are management focused rather than focused on the technical side. This vision of knowledge and improvement of competencies from stakeholders is endorsed by Succar *et al*. (2013). They advise that first step for a good implementation process is to analyze the competencies of each stakeholder, define the competencies for each stage of the implementation process of BIM, comparing to stakeholder competencies, analyze this gap and, finally, provide alignment between them. Everything reinforces the strategic vision of the companies.

Khosrowshahi and Arayici (2012) claim a fragmented consideration of actual BIM implementation is opposed to the complete and complementary strategic planning approach. Besides this, a lack of business process models has contributed to BIM being used only at a very basic level. Consequently, the implementation process of BIM is influenced by three factors: organizational culture, education and training and information management. These require a contribution of business strategy from a strategic fit between business strategy and the external domain, with an alignment among the factors presented above. As such, different BIM technologies that are available may provide different organizational capabilities; requiring stakeholders to assess currently available technologies on the market. So, the selection of suitable technology must be aligned to the future strategy of the company. For them, the main barrier for BIM implementation is a potential lack of knowledge about marginal utility, risk and benefits of implementing BIM. Therefore, collaboration among stakeholders is fundamental to increase the benefits of an in-depth vision and to spread the investment risk. Support of ongoing training and consultancy help is needed in this process too. Finally, they present a roadmap to implement BIM in the third stage (Succar 2009).

RELATIONSHIP BETWEEN BIM AND LEAN

Sacks *et al*. (2010a) present a seminal paper with a matrix relating lean principles with BIM functionalities, resulting in 55 interactions. Besides this, Sacks *et al*. (2010b) reinforce this interaction presenting the KanBIM, that uses resources of BIM (mainly visualization) to help the implementation process of the Last Planner System. This would be more interactive for users.

Hamdi and Leite (2012) applied in a case study, the framework of Sacks *et al*. (2010a), confirming many interactions. For example, use of visualization and standardization of the reduced time cycle and clash detection of the reduced time cycle too. Thus, the standardization supported by BIM helps the increase of predictability and efficiency of the building site.

Oskouie *et al*. (2012) applied Sacks's matrix too and observed that the database of BIM could support a better control of the life cycle of cost and environment; BIM facilitates the reduction of the time cycle for facility implementation and increased efficiency of the maintenance process; BIM improves the future maintainability of buildings using the integration of construction, operation and maintenance and increased agility and reliability of the process; The use of augmented reality to train operational workers reduces rework on the building site.

Khosrowshahi and Arayici (2012) present examples of what issues can be overcome by BIM implementation such as: reduced error, rework and waste for better sustainability for design and construction; improved risk management; removal of waste from process, construction and design; whole lifecycle asset management, better facility management/asset management; ability to better deal with client made changes to the design and the lifecycle implications of these; gaining supply-chain support in producing documentation and a supply-chain skill set; and construction management appreciation of the use of technology. Such solutions are similar to the results presented by the lean methodology. Consequently, there is a relationship between them and one can help another in an ongoing exchange of knowledge. In addition to this, they are complementary to companies.

Arayici *et al*. (2011) argue that the implementation process of BIM is complex where it involves process flow, competence training and a new business models. For them, the implementation process of lean needs these too and, consequently, the experience in lean implementation could be help companies implement BIM. Gu and London (2010) reinforce the importance of process flow too.

DISCUSSION

The above discussions show that BIM must be considered as a strategic process that involves organizational change and innovation, beyond technical aspects. However, many publications (technical and academic) are concentrated solely on technical aspects, explaining how to use software related to BIM or how to develop BIM in a specific project.

In truth, this is a myopic vision and will cause difficulties in the implementation process of BIM during its advanced stages, because many problems are organizational and innovationally related. Technical factors are not sufficient to support a deep and ongoing implementation process. Therefore, it is necessary to invest deeply in the organizational process and in people, the actual agents of change, because they affect organizational culture directly. The biggest challenges of all organizational implementation processes are related to the human aspects. Consequently, the chief executive office (CEO) must believe in it, because he or she must drive the process forward, convincing everyone of this new reality. This problem affects all the processes of organizational implementation such as lean, ISO 9000 etc.

Another important issue is the role of public power (government) as a catalyst of the implementation process of BIM in the industry through recommendations and rules, forcing companies to use BIM. Of course, it too must obey the use of BIM in all new constructions of public buildings.

To aid the facilitation of the implementation of BIM (Figure 2), a 3D matrix is presented to support a strategic planning of this process, considering a long term vision, the roles of the CEO and public power, and the lean experience (named Strategic Cube for the BIM implementation). In the X axis, fields (in their respective step types) are presented: technology, process, policy (Succar 2009) and people (Khosrowshahi and Arayici 2012). Here, human resources too (step type) has been transformed into a field, because it is an important agent for organizational change. In the Y axis, several stakeholders are listed: owner, general contractor, subcontractor, designers, engineers, suppliers, universities and government. Finally, in the Z axis, BIM stages of implementation (Succar 2009) are presented: pre-BIM, modeling, collaboration and integration. As well as this, it is necessary to consider the points of adoption (Succar and Kassem 2015) too, and their cyclic process of innovation and stabilization (PDCA cycle) in an ongoing evolution of the process of BIM implementation.

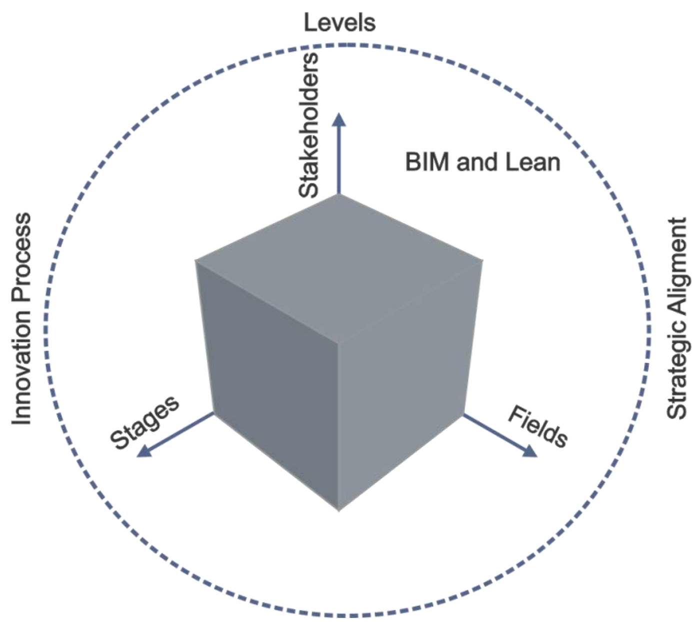

Figure 2: 3D Matrix of Strategic Planning for the Implementation Process of BIM

Accordingly, the idea is to build, in the forthcoming paper, questions to drive the strategic planning of BIM implementation, considering the axis crossing and the bottom-up (project to industry) sequence of the implementation process. Furthermore, aspects related to organizational change and the innovation process must also be considered.

For example, some questions that could be asked are: what training should sub-contractors receive in the pre-BIM stage? How much should owners invest in an IT infrastructure in order to move from the pre-BIM stage to the modeling stage? Finally, these questions will be offered as a theoretical proposal only, because the development of strategic planning to the implementation of BIM depends on characteristics and peculiarities of each industry, company and project. Thereby, in the future, a set of questions will be presented and they will be used according to circumstances.

CONCLUSION

This paper discusses the organizational and strategic aspects behind the implementation process of BIM, the reason for which is that few discussions have been made in literature. The main interest of researches is to study the applications of BIM (technical aspects). Nevertheless, this procedure is not sufficient for a long-term use of BIM as a strategic resource. As such, a 3D matrix of strategic planning for the implementation process of BIM was presented to open the debate about strategic aspects related to BIM.

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LEAN CONSTRUCTION AS AN EMERGENT OPERATIONS STRATEGY

Helena Lidelöw[1] and Kajsa Simu[2]

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. Under the assumption that an operations strategy is emergent, it should be traceable on the tactical level of a company. The aim of this research is to detect the emergent operations strategy at construction companies and contrast it with existing research on decision categories. An interview study with nine middle managers at different Swedish contractors was organised. All respondents are active on the tactical level of their respective companies. The in-depth interviews were transcribed and the transcriptions analysed to identify categories that are focused in daily operational decisions. According to operations management literature, it is in the daily decision making that the operations strategy is created and enacted. The differences between companies with and without a Lean implementation were analysed. Some of the managers claiming to work according to Lean principles displayed many similarities with managers which are not. Furthermore, managers (and their companies) without a clear statement on Lean implementation still embrace many of the basic Lean principles. The emerging categories were compared to existing publications of decision categories. The result shows that Lean principles can constitute part of a construction company's operations strategy without them having an acclaimed Lean implementation. Treating the operations strategy as emergent from daily actions is a successful way of detecting it.

KEYWORDS

Operations, process, production, production system design, strategy.

INTRODUCTION

Every firm has a business strategy and an operations strategy, Fig. 1. The business strategy frames *what* products and on what market (*where*) these will be offered. An operations strategy is a long-range plan for the operations function, (Anderson et al. 1989). The operations strategy (Skinner 1969) frames *how* operations should be

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conducted on the tactical firm level, and is often emergent; traceable as a pattern of decisions (Slack and Lewis 2011). Emergent should be interpreted as opposed to applied – an emergent operations strategy is the strategy that is actually enacted as it emerges as a pattern of decisions made in the organisation. Lean Construction (Koskela 1992) can be perceived as an operations strategy (Slack and Lewis 2011). As such, it should be traceable on the tactical level of a firm as a pattern of decisions. If Lean Construction is not implemented, the operations strategy should have a different pattern of decisions. Tracing the emergent operations strategy could therefore be a way to discover the quality and depth of Lean implementation.

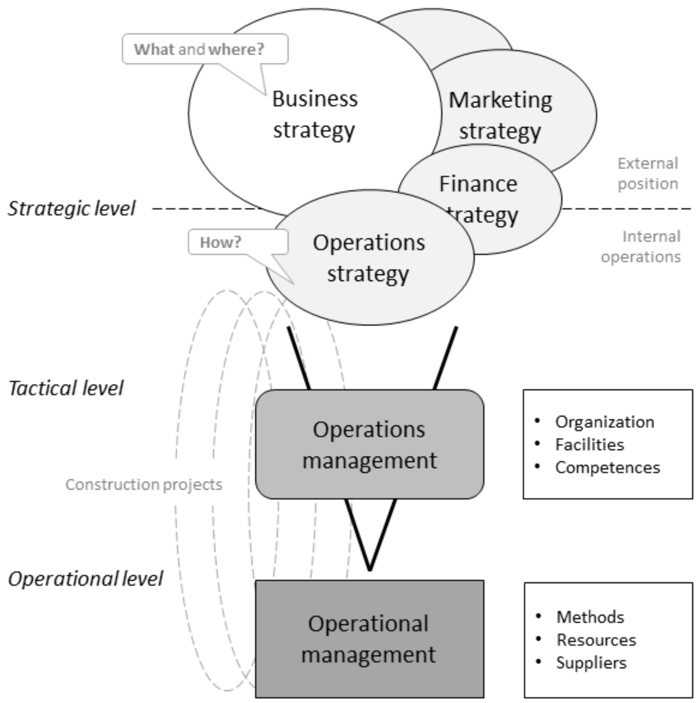

Figure 1: Levels of operations and strategies in a single-business firm.

The aim of this research is to trace the operations strategy at different contractor firms, identify the decisions made and their interpretation as emergent themes from interview data. In Lidelöw and Simu (2015), existing theories were forced upon empirical data, whereas in this research the pattern of decisions emerges from the data. Information was obtained from semi-structured interviews with a tactical level representative of each firm, including open questions about their respective firms' operations, conduct, and management. The work is concluded by reconnecting with the theoretical decision categories presented in Rudberg and Olhager (2003).

STRATEGIC ASPECTS OF LEAN CONSTRUCTION

Upon realizing that construction is another type of production (Childerhouse et al. 2000) than mass production, it also became clear that the relationship between operations and the firm itself differs from that in manufacturing firms. Organizing production in construction projects called for a redefinition of Lean principles into Lean Construction (Koskela 1992). Producing in projects offers the possibility (and the risk) to revalue the supply chain in every project to fit customer demands (Childerhouse et al. 2000).

The basic incentive for implementing Lean in the manufacturing industry is to turn manufacturing into a competitive advantage by shortening lead times and increasing quality (Almeida and Salazar 2003). Lean Construction is likewise implemented to improve the execution of construction projects by applying methods as JIT, concurrent engineering, and Last Planner (Ballard 1994). The organization supporting the projects and the business strategy need to be aligned with the Lean Construction operations strategy ((Porter 1996; Filho et al. 2011). Ballard et al. (2001) propose that Maximizing Value, Delivering the Project, and Minimizing Waste should be universal goals for project-oriented firms in production system design. Less attention has been paid (Filho et al. 2011) to the supporting infrastructure inside firms represented by decisions on organization, product development, human resources, performance measurement, production planning and control, and quality (Rudberg and Olhager 2003) as compared to structural decision categories as process technology, capacity, facilities, and vertical integration. In other words; the infrastructure provided by the firm has been given less attention in Lean Construction implementation than the structure in construction projects. Sustainable competitive advantage in a firm is created by exploiting properties that cannot easily be copied (Barney 1991) – methods and structures are relatively easy to copy, while the infrastructural part of an operations strategy is not. Harris (1997) reports interactions between the strategic, tactical, and operational levels in Fig. 1, but these are not yet understood in construction. Following Filho (2013) and Acur et al. (2003), understanding Lean Construction as an operations strategy aligning business and operational levels through infrastructural and structural decisions will theoretically lead to a competitive advantage for construction firms.

The decision categories are the type of internal decisions that needs to be made in operations to follow the business and operations strategies – in the case of Lean Construction as an operations strategy; the decision categories reflect how Lean is operationalized. Looking outside the world of Lean, the content of the decisions determines production system design and project delivery systems (Alarcon et al. 2013). Decision categories need to be separated from the competitive criteria/objectives that the firm uses to compete on the external market. Examples of competitive criteria are: cost, quality, delivery performance, flexibility, and innovation (e.g. (Santos et al. 2003)). In construction, cost and delivery are the strongest competitive criteria so far, while innovation (e.g. presenting new models and/or technology) is often met with reluctance from customers. Flexibility or customization is growing stronger as a competitive criterion depending on the market niche (Kemmer et al. 2010).

METHODOLOGY

Following the theoretical structure in Fig. 1, managers on the tactical level are the primary sources of information about their firms' operations strategies. As the operations strategy is frequently implicit (and may deviate in practice from specified formulations even if it is explicit), in-depth interviews focused on how operations are managed were conducted, seeking knowledge of real life events. The interview data were coded into categories emerging as themes and these categories are used to summarize and present the data in a format that enables comparison with theory. 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 in construction. The data set includes managers that work either within or without a Lean implementation in their respective companies.

DATA COLLECTION

The empirical data was collected through interviews with one tactical level manager at each of nine different construction contractors in Sweden, Table 1. Firms with or without an active Lean implementation were sought to increase the external validity of the results. The unit of analysis are operations they handle, taken to represent the general practice at their respective firms from their perspectives. 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.

Table 1. Respondents.

Respondent	Position at firm
A	Middle manager, reporting directly to top management, liable for a turnover of 100 M€
B	Top manager, responsible for one third of the total business, liable for a turnover of 35 M€
C	Middle manager, reporting directly to top management, liable for a turnover of 50 M€
D	Lean manager, reporting directly to top management, liable for process improvements of 10 M€
E	CEO and cofounder, liable for a turnover of 3.5 M€
F	Platform manager, part of top management, joint liable for a turnover of 1,300 M€
G	Middle manager, reporting directly to top management, liable for a turnover of X M€
H	Middle manager, reporting directly to top management, liable for a turnover of X M€
I	Middle manager, reporting directly to top management, liable for a turnover of X M€

The interviews were semi-structured and about one hour long. The respondents were interviewed during 2013-2015 focusing on discussions reported in Table 2. 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 missing obvious points and discrepancies and/or 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. These risks have been partly mitigated by the two authors always working in parallel with analysis to avoid interpretations being colored by a single person's views.

Table 2. Discussion questions for the interviews.

What is your view on standardisation?	How is your company organised?	How do you handle variation between projects?	How do you balance resources between projects?
What are your relations with subcontractors?	What is your main competitive advantage?	How do you work with experience feedback?	How do you relate to strategies pushed top-down?

ANALYSIS METHOD

The transcripts were read by both authors and the statements were sorted into themes. These themes were identified by finding statements that addressed the same topic e.g. planning. Both authors made the thematic analysis separately to increase the internal validity of the findings and then the themes were compared to reach a consensus view on labelling and sorting. Care was then taken to analyse the statements within the themes to discern how the respondents approached the topic. For example on the topic of standardisation, one respondent described this as being a core value in the organisation while the next respondent addressed it as something made by a central organisation. These shifting angles made it possible to detect the emergent operations strategies. The interview data were condensed and illustrative comments and emerging decision categories are presented in Table 3. Furthermore, the strength of the themes is illustrated in Figure 2 by using colours (Fig. 2 is not meant to be readable). Each block corresponds to a statement made in the interviews so many blocks of the same colour indicate that this was an important topic.

INTERVIEW RESULTS AND ANALYSIS

EMERGING DECISION CATEGORIES

Table 3 shows that the emergent decision categories have different meanings for companies with a Lean implementation and those without. Prominently, a Lean implementation gives the employees in the firm a language when talking about their operations strategy. It was very clear during the interviews that construction firms working in a traditional way reflect less on what they are actually doing and do not see their operations strategy as a deliberate choice.

Continuous improvement emerged as a decision category with all interviewed firms. However, continuous improvement was in the mindset of firms with a Lean focus, while the other firms did it *ad hoc* at sparse intervals and often by a separate function. The largest contrast arose when the firm representatives spoke about *standardization*. While Lean firms saw standardization as a means to improve flow, the firms focusing resources regarded standardization as difficult and of no value since every project is unique. Furthermore, standards were something set by a central function in the firm and was not always followed in every project for reasons of not suiting the project or not to the managers liking. Decisions on the *supply chain* were in firms focusing flow biased towards collaboration and transparency, while firms focusing resources procured a new supply chain for every project to get the lowest price through subcontractor competition.

Table 3: Emerging decision categories

Decision category	**Firms focused on flow (Lean)**	**Firms focused on resources**
Continuous improvement and learning	Is a mindset Systematic approach	Ad hoc "Someone else's responsibility"
Standardization	Standards are a means for improvement of flow Standards include the way to work (how to add value)	Each project has a status of being unique – no need for standardization
Supply chain	Customer value perspective Collaboration and transparency	Unique project focus Procurement in each project
Process versus project	Flow and HOW to deliver value Visualization to see Wholeness	Unique projects – focus on WHAT to deliver
Human resources *Values and corporate culture*	Commitment – responsibility of and for all employees People are assets Culture carries the way to work – respect and trust	Individuals are carrier of knowledge and skills
Performance measurement	Improvements of processes and ways of working Related to quality and quality defects	Focus on economic bottom line profit Reactive measures (cost, volume, time) Variation due to which individual is involved
Organization *Leadership*	Not in focus Train the mindset, walk the talk	Resources and organization in projects gives the end results Lack of consistency and self-responsibility in leadership
Planning of project/production	Resource planning – to level out variation in projects	Control in a sequential manner Planning of resources with focus on time and capacity
Long-term perspective	Increased production to survive Long-term changes and investments	Project focus – not always related to long-term vision

Many thoughts were offered from respondents on decisions regarding process versus project focus. This is a crucial point for firms working with Lean, while other firms seem oblivious of the fact that one can view a series of projects as a process. Another interesting difference was the view on human resources; firms working as traditional contractors view their personnel as capacity that are individual carriers of competence and skill. Firms working with lean view their employees as assets. Much effort is put on planning human resource utilization. Performance measurement is in firms focusing resources made by determining costs and counting other reactive measures. Firms with a Lean implementation complement those measurements with process measures as defects and cycle time. When it comes to organization in projects, this was not a strong decision category at firms focusing flow, while it was central at firms focusing resources. The choice of site manager was even identified as the most important factor for success or failure of the project. Decisions on planning at traditional contractors was an activity that supports human resource utilization and organization, while firms focusing flow make decisions to balance resources between projects. The long-term perspective was strongest with firms focusing flow – the traditional contractors made decisions pertaining to the projects, not to support the firm itself.

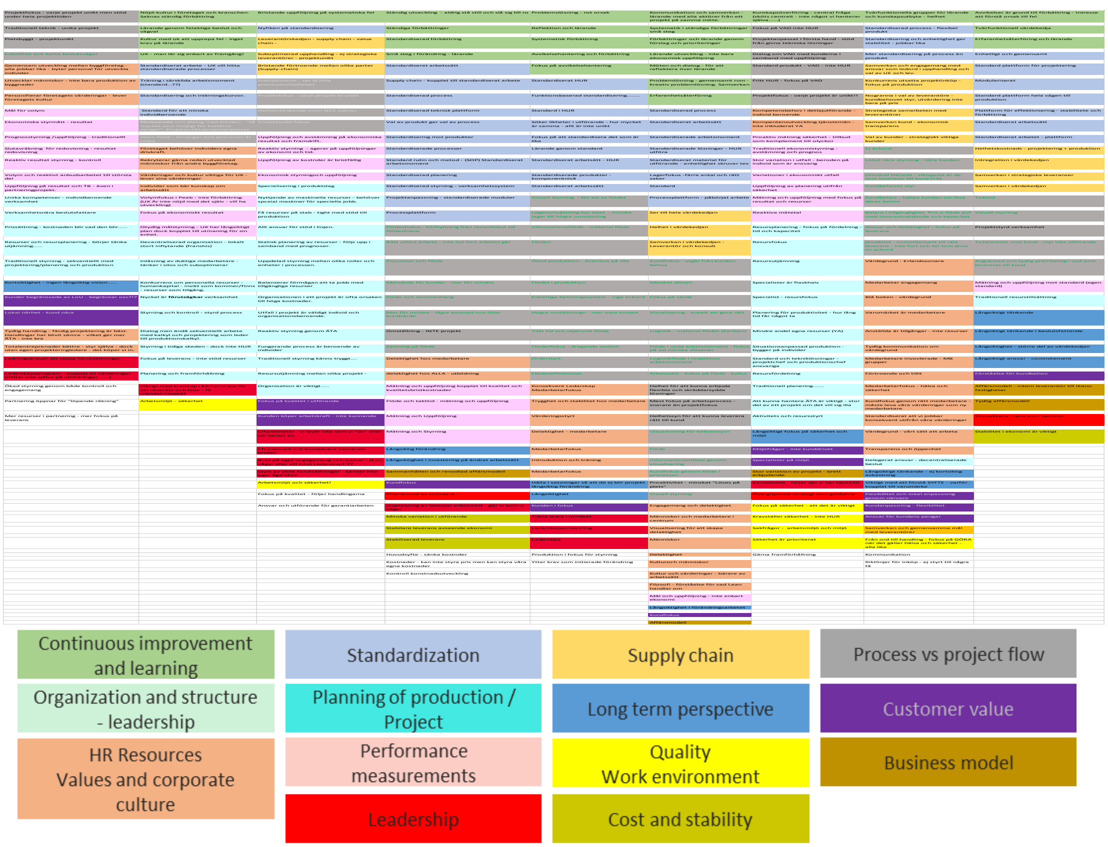

Figure 2: Schematic view of the importance of emergent decision categories.

Many of the tactical managers in traditionally managed construction firms did not have a long-term vision by themselves. Either the long-term strategy was given to them top-down or they had great trouble figuring out how to use their production knowledge as an asset. In the original data set, three firms had an outspoken Lean operations strategy. By comparing themes and how the tactical managers answered, it was found that five firms actually were working according to Lean principles.

From figure 2 it is readable that companies working in a more traditional way (columns 1, 2, 3, and 7) talk about what they deliver, rather than how this is delivered. Still it is obvious that there is a 'how' also at these firms – this is to focus on *what* to deliver, by *what* resources and with *what* organization. Organization in terms of resource planning, human resource management, and finding the right individual were the main decisions. The five other firms (columns 4, 5, 6, 8, and 9) concerned themselves with standardization and process vs project flow. Standardization came across as standardization of work tasks, of technical solutions, but also in processes and relationships e.g. in the supply chain. Process vs project flow was a natural topic as these firms are construction firms, delivering in projects but with the support of an underlying standardized process. Underlying values, culture and employee commitment were more important for the firms focusing flow, Figure 2.

When it comes to competitive criteria, cost reduction as a result of the investment in a Lean operations strategy is identified by firms focusing on flow. As a contrast one of the tactical managers at a resource focused firm stated that "the cost is what it is". Customer value is actively brought up as a competitive criterion by all the firms working with a flow-oriented operations strategy, while the traditional construction firms relate to customer value as "working with the wallet of the customer".

THEORETICAL RECONNECTION

Table 4 compares decision categories from earlier publications with those in Table 3.

Table 4: Decision categories condensed by Rudberg and Olhager (2003) compared to those found in this research

	Structural categories	**Infrastructural categories**
Decision categories from the manufacturing industry	Process technology	Human resources
	Capacity	Organization
	Facilities	Quality
	Vertical integration	Production planning and control
		Product development
		Performance measurement
Decision categories proposed for Lean Construction in this research	**Standardization**	Human Resources
	Capacity/organization in projects	**Continuous improvement**
	Work Environment	**Long-term Perspective**
	Vertical Integration	Production planning
		Process vs Project
		Performance measurement

The differences between the decision categories published for the manufacturing industry and the proposed ones are bold in Table 4. Standardization is a more narrow way of presenting the decision on process technology; to use a standardized solution (and its dedicated production process) or not. Work environment (as opposed to Facilities) is an important decision for many construction companies with the increasing safety awareness in the business. Continuous improvement is seen as a challenge in construction and arises as a more important decision than quality – several of the respondents connect quality with customer focus placing it as a competitive criterion rather than a decision category. Long-term perspective is coupled to continuous improvement and is an active decision by construction firms focusing flow. In the manufacturing industry, product development is an important decision that supports the long-time survival of the firm, but this does emerge as a priority with construction firms who integrate product development in the construction design phase. The decision that most tactical managers struggle with is whether to prioritize the process or the projects. Making that priority is where Lean as an operations strategy emerges most strongly; focusing the process will reveal instantaneously if a manager acts according to Lean principles or not. Infrastructural decision categories is where manufacturing and construction firms differ the most; identifying them as firms with different logics and different ways of creating competitive advantage.

CONCLUSIONS

The decision categories in an operations strategy in Lean construction are proposed as: Standardization, Capacity/organization in Projects, Work Environment, Supply Chain, Work Environment, Human Resources, Continuous Improvements, Production Planning, Long-term Perspective, Process vs project, and Performance Measurement. The most important difference from earlier publications of decision categories stemming from the manufacturing industry is that there is a larger focus on the strain between project and process focus. The method used in this research shows that it is possible to detect the emergent operations strategy of a construction firm and trace the enactment of Lean Construction.

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THE LINK BETWEEN STAKEHOLDER POWER AND VALUE CREATION IN CONSTRUCTION PROJECTS

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ABSTRACT

This paper presents a study on what effect stakeholder power has on value creation in construction projects. Fourteen main sources of power in organizations, described by Morgan, form the analytic framework. The ambition is to identify 1) how the distribution of power between the main stakeholders is, 2) which sources of power are most common in a construction project organization, 3) which effect the sources of power have on value creation in projects.

The data is collected through semi-structured interviews. Experienced representatives from four main stakeholders in early phase of construction projects (owner, architect, design manager and project manager) were interviewed. The collected data through the interviews was coded, analyzed and linked to the literature study. The results reveals that 10 of 14 sources of power are identified as common sources of power in construction project organizations. Out of the ten, control of knowledge & information and formal authority are rated as the most influential sources of power. Apparently, all main stakeholders can possess these two sources. Rhetorical skills – which is not among the fourteen main sources described by Morgan – turn out to be an underrated and complex source of power.

The LCI triangle model suggests that all project delivery systems have three basic domains whining which they operate i) organization, ii) the project´s "Operating system" and iii) the commercial terms binding the participants. These are equally important and should be aligned for the system to be coherent. Power is one of the main elements in organizational affairs that effect transparency and decision processes. There is a knowledge gap in how the power can affect the processes in project organization and which effects it can have on the projects´ overall value creation.

KEY WORDS

Power, Organization, Value creation, Early phase, Rhetoric

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INTRODUCTION

This paper presents results from research on the link between power in organizations of construction projects and value creation. Although the concept of power has been subject to many definitions, a common notion is that power make things happen by influencing the behavior of another social unit (Loosemore, 1999). This influence can result in desired and undesired outcomes, both for the stakeholder exercising power and the one subdued to it. Consequently, the exercise of power can be both a challenge and an opportunity for stakeholders in construction projects. Eikeland (2001) stresses that improvements, either at the final product or in successful process, can result in value. Hence, the link between power in project organizations and value creation in the project needs to be understood.

Power in organizations has been a hot topic for researchers, especially within fields of management, over the last decades (Astley and Sachdeva, 1984; Daft, 2012; Engelstad, 2005; Ivancevich et al., 2011; Mechanic, 1962; Morgan, 2006; Pammer and Killian, 2003). Numerous researchers have conceptualized, defined and evaluated the effect of power in the organizations. Understanding the effect of power on value creation demands an understanding of value creation through project delivery systems. The LCI (Lean Construction Institute) triangle suggests that all project delivery systems have three basic domains within which they operate; i) the project organization, ii) the project's "operating system," and iii) the commercial terms binding the project participants (Thomsen et al., 2009) . Integrated organization as a tool in lean construction requires transparency and reduces the significance of formal bindings between the participants. This might trigger the desire of certain stakeholders to use power to impose a desired outcome. It is therefore important to investigate how stakeholders use power to influence decisions. Equally, the sources of power to influence decisions needs clarification in order to address what is at stake. Such clarifications are crucial to increase transparency and, correspondingly, prevent the abuse of power. According to the literature study leading up to the research presented here, there seems to be a certain knowledge gap in the lean construction literature concerning the relationship between sources of power in integrated organizations and their significance for processes and value creation. This leads us to following research questions:

- How is the distribution of power between the main stakeholders in a project?
- Which sources of power are most common in a construction project organization?
- Which effects do the sources of power have on value creation in a project?

RESEARCH METHODOLOGY

Value, value creation and power are the major concepts addressed in this study. A literature review was conducted according to procedures described by (Blumberg et al., 2014) by reviewing other studies that are closely related to the topics power, value and value creation in order to acquire a good understanding of the theory concerning these concepts. The literature review investigated existing descriptions and definitions of value, value creation, power and sources of power in organizations in order to attain an overview of what has been discovered before within aforementioned concepts.

This paper is a result of linking the literature study and interviews with representatives for four major stakeholders in a construction project (architect, design manager, project manager and project owner). According to Samset (2010), these are the stakeholders that directly impel the project. The user is a stakeholder with significant importance in the projects. However, user groups are usually formed as one-time organizations, which makes it difficult to find representatives with experience from several projects. Hence, the user as a stakeholder has not been a part of this study but the significance of their power in is undeniable.

Data was collected through four semi-structured interviews. The interviews were audio recorded, transcribed and then coded by marks, notes and memos of topics according to the procedures outlined by Yin (2014). Each interview lasted approximately 1.5 hours.

THEORETICAL BACKGROUND

The discussions and pursuit towards defining value has been ongoing since the antiquity. According to Fleetwood (1997), Aristotle (4th century BC) was the first philosopher documented to have differentiated between two meanings; "use-value" and "exchange value". The term "use value", denotes how customers according to their needs perceive specific qualities in a product. Judgments concerning use value are therefore subjective of nature. Exchange value, on the other hand, refers to the price, that is, the monetary amount realized at a certain point of time when the exchange of the good takes place (Bowman and Ambrosini, 2000). Value and value creation have particularly been discussed in management and marketing literature during the last decades, especially since the 1980s (Zeithaml, 1988; Dodds et al., 1991; Holbrook, 1994&1999; Babin et al., 1994; Woodruff, 1997; Parasuraman, 1997; Kaufman, 1998; Kelly et al. 2015, etc.). Although different theories and research streams have been applied in different contexts to conceptualize "value", one general insight is that the term coins the focus on the customers and users and their perception of value in relation to satisfying their needs (Haddadi et al., 2015).

Value creation in a project depends on the relative amount of value that is subjectively realized by a target user who is the focus of value creation – whether this concerns an individual, an organization, or society as a whole (Lepak et al., 2007). Various stakeholders in a project have different views on what is valuable. The difference stems from particular knowledge, goals, context and conditions that influence how the novelty of the value is conceived and evaluated by the respective actors. They may also have competing interests and viewpoints of what is valuable (Lepak et al., 2007). This difference can result in a divergence in what stakeholders define as valuable outcome and hence attempts to impose their own favorable outcome (exert power) to other stakeholders or party. The overall value creation in a project will hence depend on which stakeholder's value has been in focus and in which degree it has been realized.

Power has typically been investigated as an independent variable in research design. It has been used to explain decision making in small groups, and for explaining moral and alienation in studies of work organizations (Hickson et al., 1971). Pammer and Killian (2003) describe power as *"one party's attempt to impose an outcome on the other party"*.

To impose an outcome can be envisaged in multiple forms, such as by brute force, legislative measures or – most significantly within the context of this paper – by rhetorical means. Aristotle – the foremost theoretician of ancient rhetoric – defines rhetoric as the faculty of discovering or observing the possible and available means of persuasion. According to him, modes of persuasion which strictly belong to what he mentions as "*the art of rhetoric*" has three divisions; i) power of evincing a personal character which will make the speech credible (ethos) ii) power of stirring the emotions of the counterparty or hearer (pathos), iii) power of proving a truth by arguments (logos) (Aristotle et al., 2014). Koskela (2015) argues that rhetoric is one of the fundamental aspects in management (in particular related to lean) by addressing elements like fundamental arguments in production management, compliance to plans, reinforcing common values, deliberating courses of action and inventing requirements and ideas.

"Sources of power" is extensively discussed and investigated in literature. There are numerous classifications, categorizations and definitions of sources of power. Despite the similarities, they address the issue in different ways. Some try to simplify the concept while others have more comprehensive categorization of sources of power (Astley and Sachdeva, 1984; Daft, 2012; Engelstad, 2005; Ivancevich et al., 2011; Mechanic, 1962; Morgan, 2006)

Morgan (2006) defines power as "*…the medium through which conflicts of interest are ultimately resolved. Power influences who gets what, when and how*". He introduces 14 sources of power in organizations. Morgan's categorization offers a comprehensive and explicit definition of the sources of power, which is highly applicable in construction project organizations. The categorization seem to cover a wide range of possible reasons for why a stakeholder should possess the ability or willingness to impose an outcome. Hence, the authors have evaluated this the most relevant reference to base this research on. The 14 sources of power according to Morgan (2006) are presented in Table 1.

Table 1: Morgan´s 14 sources of power (Morgan, 2006)

No.	Source	No.	Source
1	Formal Authority	8	Control of technology
2	Control of scarce resources	9	Interpersonal alliances, networks, and control of "informal organization"
3	Use of organizational structure, rules, and procedures:	10	Control of counter-organizations
4	Control of decision processes:	11	Symbolism and the management of meaning
5	Control of knowledge and information	12	Gender and gender relations
6	Control of boundaries	13	Structural factors that define stage of action
7	Ability to cope with uncertainty	14	The power one already has

FINDINGS AND DISCUSSION

The results are mainly the interviewees' answers to the inquired research questions.

DISTRIBUTION OF POWER IN A PROJECT ORGANIZATION

The interview objects were asked to describe how they see the distribution of power between the main stakeholders in Norwegian construction projects. As expected, there are some differences in how the distribution of power is perceived among the stakeholders.

Owner: All the interviewees mentioned that the owner is the stakeholder with the highest power although differences in exertion of the power by the owners occur. Some owners transfer the power to the project manager and the management team; some have a more "hands on" approach on their projects. The owner's competences and knowledge is a decisive factor on how much power it actually has despite the formal authority. The owner representative mentioned that the owner has less power than presumed, especially in the public sector. Users' needs are ought to be satisfied. This means that owner has less power in choosing solutions than users and architects. The owner's real power (especially in the public sector) is in managing the project in terms of economy, schedule and quality. In private sector, the owner has more power for choosing desired solution.

Architects: There is an agreement that architects have far less power nowadays than they used to have some decades ago. Different execution models, more complicated technical facilities, higher degree of technical requirements, environmental issues and new regulations was mentioned as possible reasons. The fact that the project management has been professionalized during the last decades was also mentioned among reasons why architects have less power in projects nowadays. Despite reduced power, the architects are still one of the most powerful stakeholders in the projects because of their significant role in transforming owner's requirements into functional description. Architects also feel a higher degree of ownership to the project due to the nature of their task, which is creation. This makes them more engaged in the projects and increases their willing to influence the project. They are consequently more willing to use the power sources that they are given in order to have an impact on the project they feel ownership towards.

Design team: Technical consultants have significant influence on value creation due to increasing complexity of technical facilities and more standardization and regulations. The recent focus on environmental issues has also increased the demand after technical personal in project organizations. The design team is a complex and vital organization within the project organization. Therefore, different roles and disciplines within the design team can exert power within the team as well as on the project in general.

Project management (PM): Project management here is defined as the professionals and consultants that are hired or engaged to lead the projects and are not employees of the owner organization. Interviews show that different stakeholder look differently into this stakeholder. PM role as an integrated part of the owner's organization can be conceived as the owner's operational level and thereby synonym with the owner. It means the PM takes decisions on behalf of the owner and therefore has almost the same power. On the other hand, this stakeholder can be perceived as a layer in the communication between the design team, architects and the project owner where there is a clear line between the owner and PM team. Being the owner's operational hand and a communication layer between the design team, architects and owner gives this stakeholder a massive power.

COMMON SOURCES OF POWER AND THEIR EFFECTS

Morgan's (2006) 14 sources of power is a comprehensive classification of the sources of power and used as baseline for this research. The research shows that not all 14 sources can be recognized as significant sources of power in Norwegian construction projects. The ones that seemed familiar to the interview objects were following:

Formal authority: Is a form for legitimized power that can consist of charismatic authority, traditional authority, and rational-legal authority and one of the most discussed sources of power during the interviews. Formal authority is given through deals, contracts, laws and regulations. Although the project owner is at the top of the organization map and has the highest formal power, the owner distributes the responsibility and risk down to mainly two stakeholders, the architect and the design team. The PM receives mainly formal authority with almost no risk and no legal responsibility. PM has however a moral responsibility and integrity to deliver the project within the criteria which are agreed upon. The architect is normally the one with the overall legal responsibility for securing the fulfilment of the regulations, laws and required documentations to the building authorities. The design team is responsible for delivering the functional solutions according to descriptions, laws and regulations. Although contracts are signed and knowing the content of the contracts, as the PM representative mentioned, is considered as a necessity, the stakeholders seem to be cautious with implication of power because of formal authority. It is difficult to manage the projects through contracts according to the owner representative. In most of the projects, there are minor breaches of the contract from both parts. Goodwill in solving the conflicts is a necessity. Changes happen throughout projects and sanctions are not used unless they are necessary since the consequences can be huge for the projects.

Control of scarce resources: Is defined as control over resources such as money, materials, technology, personal and suppliers that the organization depend upon. Geotechnical engineers has been mentioned as an example of a scarce resource in Norwegian construction projects nowadays. Scarcity of resources is considered as a challenge for value creation and not a common source of power used in the projects.

Control of decision processes: Ability to influence decision premises, processes, and decision issues and objectives. Normally controlled by the owner. According to the owner's representative, it is positive for value creation that the owner can control these processes. The mandate for decisions is usually based on how much the decision is going to cost the project. However, the following consequences, which are not the direct cost for the decision, can be underrated or even forgotten. This can affect the value creation negatively. Hence, a stakeholder with overall view on the project should possess this source.

Control of knowledge and information: Involves systematically influencing the definition of organizational situation and creating patterns of dependency by controlling knowledge and information. All interviewees stressed the importance of knowledge and information as a source of power in projects. People who have been in the project for a long time, PM who has the overall view, consultants with special competences and experienced architects are all mentioned as examples of the powerful participants in a project where the power is provided by knowledge and information. Easy access to internet and information online has reduced the power provided by general information. At the same time, it has contributed to higher power to specialists, consultants and experts.

Control of boundaries: Represents monitoring and controlling transactions across boundaries by performing a buffering function that allows certain transactions while blocking others. This source of power is close to the previous one. Control of boundaries becomes a source of power by controlling the information flow between the groups. This is not considered as a big issue in Norwegian projects but using this source of power means limiting the information flow between groups and reducing transparency, which generally has a negative effect on value creation.

Ability to cope with uncertainty: Is defined as the ability to cope with the external influences that affect the project such as market situation, finance, raw materials etc. and/or the internal influences such as machinery break down, use of new methods, technology etc. Ability to cope with uncertainty is a source of power especially if it results in higher decisiveness. How uncertainty is managed and how the risk is distributed in projects varies. Hence, this source of power is ambiguous for the interviewees. However, better decisions will contribute to higher value creation and risk and uncertainty should be placed where it ca be handled best.

Control of technology: The technology employed in a project provides the ability to achieve better results in productive activities, and it also provides an ability to manipulate this productive power as a source of power. This has mainly been related to two types of technology, BIM (Building Information Modelling), and technical instruments and facilities. Possessing the ability to use BIM is considered as a skill but this has not been experienced as a source of power in projects. Using BIM contributes, among others, to better transferring of information and has a positive contribution to value creation. Control over complicated facilities is considered as a power source that can have a negative impact on value creation. If one or a few suppliers has the technology to deliver a certain tool or facility, they have the power to price or affect other relevant facilities. This can reduce the options for the solutions and derby effect the value creation negatively. The same is valid for people who have good skills of programming or using technological devices.

Interpersonal alliances: Throughout different networks, individuals can develop interpersonal relations and exert various forms of interpersonal influence to shape the decisions in a project based on their interests. Although some practitioners stress the importance of project staff knowing each other for better communication, there has been unfortunate examples of using interpersonal alliances as a source of power in Norwegian construction projects. The Norwegian construction industry is relatively small, meaning people happen to meet each other or work together and establish a personal or/and professional relationship. Although people seem to be aware of this fact and act deliberately, it can, at its worst, cause corruption and difficult situations for the project.

Control of counter organizations: Involves a group of people that manages to build a concentration of power in a relatively few hands and coordinate their action to create a rival power. Control of counter organization is also a source of power that can affect the value creation. However, its effect can be both positive and negative depending of what the counter organization's intentions are. Organizations with the right to get involved, like unions that are taking care of the people's rights, can contribute to value creation by influencing the project to satisfy the needs for a larger group of people. Interest organizations, which are protecting interests and not rights, can have a negative effect on value creation in a project, especially if they represent minor concerns.

Gender and management of gender relations: Is defined as gender-related issues that bias organizational life in favor of one sex over another. This source is culture-related. Although none of the interview objects considered this as a problem in Norwegian projects, the authors believe that this is a tabooed topic. That might be the reason why no one considered gender related power as a problem.

CONCLUSIONS

Regarding the first research question, the *distribution* of power can vary between projects due to factors like the circumstances, complexity, owner and user involvements, management methods etc. However, there is a consensus in how the distribution of power is conceived by interviewees.

With reference to the second research question about common sources of power, the research has revealed that out of Morgan's 14 sources of power, only 10 are recognized as common sources of power in Norwegian construction projects. Sources that are not mentioned are either not acknowledged by the interviewees as a source of power in Norwegian projects, or are considered as a following consequence of another source of power. For example, "Use of organizational structure rules, regulations and procedures" can be a result of other sources of power like "Formal authority", "Control of the decision processes" or "Control of boundaries". "The power one already has" as a source of power to get more power is dependent on individuals and cannot be considered as a general challenge for construction projects. The same argument applies to "symbolism and management of meaning". This brings us further to the discussion on rhetorical skills as a missing source of power on Morgan's list.

Regarding the third research question about the effect of the sources of power on value creation, all interviewees stressed the importance of "control of knowledge and information". Control of knowledge and information is considered the category with highest effect on value creation in projects. The research reveals that "Formal authority" is also a critical category. The effect of the "Formal authority" as a source of power equally indicates the importance of another domain of the LCI triangle (Commercial), which is the agreements and commercial terms between the participants. With a more open agreement form where everyone is responsible for project success, the effect of formal authority as a source of power is less than non-integrated organizations. This will also reduce formal power relation's ability to limit the possibilities of underdog parties to present their knowledge. All sources of power can be abused and have a negative effect on the project and value creation. Table 2 summarizes the effects of the sources of power on value creation assuming that the source of power is not intentionally abused.

Table 2: Distribution of the common sources of power, and the effect on value creation

Source of power	**Importance**	**The effects on value creation**	**Stakeholders who possess the source of power**
Control of knowledge and information	High	Knowledge is appreciated and those with knowledge have the opportunity to influence. Positive for value creation	Owner, PM, Architect, Design
Formal Authority	High	Positive when it clarifies the roles and mandates in a project. Negative if the power and responsibility is not aligned.	Owner, PM, Architect, Design
Control of decision processes	Medium	Good control of decision processes will shorten the decision time and have a positive contribution on value creation.	Owner, PM
Control of boundaries	Medium	Using this to organize the project with proper information flow and good cooperation will have a positive effect on value creation.	Owner, PM, Architect
Interpersonal alliances	Medium	Reduces transparency and gives the power to minority. Negative effect on value creation.	Owner, PM, Architect, Design
Control of technology	Medium	Stimulates innovation and new thinking. In that case positive. Negative for value creation if it ends up in a monopoly situation.	Architect, Design
Control of counter organizations	Medium	Positive if they protect rights. Negative if they represent minor interests.	External
Coping with uncertainty	Medium	Can lead to better decisions. Positive for value creation	Owner, PM, Architect, Design
Control of scarce resources	Low	This is rather a challenge for value creation than a positive or negative contribution	Architect, Design
Gender and gender relations	Low	Culture-related. In Norwegian projects, this is not considered as a factor related to value creation.	Owner, PM, Architect, Design

Results reveal that more democratic organizational models that promote transparency, like IPD, can improve value creation in a project. This can be related to both the Organizational and Commercial sides of the LCI triangle. By more democratic organization models, formal authority will not interfere with the flow of information and knowledge. As a result, the control of boundaries and decision processes will have reduced effect as sources of power.

It is of interest that Morgan’s classification does not include rhetoric as a separate source of power. This might be because the engineering disciplines are still strongly positivistic in their approach to human behavior. Within the context of rhetoric, this typically comes out as a firm belief in the impartial power of pure argumentation. Contemporary philosophical analyses, in particular the postmodern (Derrida, Deleuze, Foucault, etc.), typically express a deep skepticism to such idealized representation of argument as corresponding to inherent qualities of the life-world. Rather, in such thinkers, rhetoric is revitalized as expressing a necessary part of understanding how the world actually functions. Little research has been carried out to determine whether the influence of rhetoric is powerful enough to be established as a 15th source of power in classifications such as that of Morgan’s. Further research is necessary to understand power dynamics and the influence of it on value creation in particular within Lean Construction.

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SECTION 2: PRODUCTION SYSTEM DESIGN

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FILMMAKING AND CONSTRUCTION: TWO PROJECT PRODUCTION SYSTEMS

Glenn Ballard[1], Christin Egebjerg[2], Trond Bølviken[3], Sigve Endresen[4], and Brittany Ballard[5]

ABSTRACT

Both filmmaking and construction are project production systems, along with shipbuilding (air and sea), new product development, software engineering, performing arts productions (theater, dance, etc.), and more. Because they are similar in fundamental ways, there is potential for learning one from another, and for further developing the principles and methods peculiar to the project production systems through which all artifacts are created.

This paper is the first product of design science research underway to improve both filmmaking and construction. Based on a review of the literature and the experience of the authors as practitioners in construction and filmmaking, the paper offers a comparison of the two project production systems, in an effort to understand key similarities and differences. From that comparison, a hypothesis has emerged; namely, that the future state proposed by advocates of lean construction already exists in filmmaking. Hypothesis testing and transfer of knowledge from filmmaking to construction will be reported in future publications.

KEYWORDS

Culture, filmmaking, lean construction, production system design, relational contracts

INTRODUCTION

All project production systems share certain characteristics. All design and make goods or services through temporary organizations with time-limited objectives. All move through time in phases: all define their projects, build their teams, design their products and processes, make or buy the elements of which their products are composed, and assemble those elements into their products. However, they produce different types of products, under different framework conditions, and have developed independently one from another, so also have dissimilarities as well as similarities. How projects arise, how project teams are formed, and how projects are managed – all these may differ in filmmaking as compared to construction.

The opportunity to transfer knowledge between different types of project production system has been too little exploited. However, Christin Egebjerg's "...and ACTION!" (Egebjerg 2012) is a notable exception. After an intensive study of filmmaking and construction, Egebjerg reports that production management in filmmaking handles challenges at least as difficult as those faced on most construction projects. She has also proposed a

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transfer of knowledge in the form of a software tool that adapts filmmaking's production coordination to the parallel activities characteristic of construction (Egebjerg 2013).

Our research is a continuation of Egebjerg's, but with an expanded scope. Our study is limited to large construction projects and large feature film projects, but within that scope we will examine all aspects of filmmaking and construction in search of knowledge transfers in both directions. We differentiate between traditional management, which is still the dominant form of project delivery in construction, and lean management of construction projects. As for filmmaking, we consider only the dominant form of delivery; namely, the so-called Hollywood system (Persse 2008).

This paper reports our first steps. Its objective is to make a plausible argument for a hypothesis: *the future state proposed by advocates of lean construction already exists in filmmaking.* This hypothesis, if true, suggests that knowledge may be transferred from filmmaking to construction to help accelerate realization of the future state construction project delivery. Hypothesis testing and knowledge transfer will occur in later research.

After this introduction, the paper is divided into sections devoted to a review of the literature, design science research methodology, arguments for the hypothesis, conclusions, and references.

LITERATURE REVIEW

The relevant literature for this paper includes publications on project management, lean management of construction projects, and the management of film projects. Given the hypothesis--*the future state proposed by advocates of lean construction already exists in filmmaking*--selections have been made from the large number of publications on these topics. The Project Management Institute's PMBOK Guide (Rose 2013) represents traditional, mainstream project management. *Managing Integrated Project Delivery (*Thomsen et al. 2009), *The Underlying Theory of Project Management is Obsolete* (Koskela and Howell 2002), and *Lean management methods for complex projects* (Ballard and Tommelein 2012) represent lean management of construction projects. *Paradox in Project-Based Enterprise: The Case of Film Making* (De Filippi and Arthur 1998), *Hollywood secrets of project management success* (Persse 2008), *Expecting the unexpected? How SWAT officers and film crews handle surprises* (Bechky and Okhuysen 2011), and Egebjerg's "and…ACTION!" (2012), represent the management of film projects.

An earlier version of the PMBOK Guide was critiqued by Koskela and Howell (2002) at a Project Management Institute conference. That critique is summarized in the section below titled *Arguments for the Hypothesis*. The current version of the PMBOK Guide says explicitly that production management lies outside project management. This exclusion is challenged by lean theorists (Koskela and Ballard (2006).

The model used to compare the management of construction and the management of film projects was developed from Thomsen, et al. (2002). Description of the future state vision of lean adherents for construction project management is drawn from Ballard & Tommelein (2012).

The publications on the management of film projects all stress the high level of uncertainty and complexity routinely met on those projects, and also the high degree of effectiveness in project delivery. Of special importance is Egebjerg's ethnomethodological observations of film projects, key findings from which are the intense identification of team members with project objectives, and the combination of push and pull methods of managing.

Egebjerg (2012) and Persse (2008) have a similar approach. They both perceive that filmmaking is performing better than respectively construction and software development, and want to examine what the two industries can learn from filmmaking. The approach of

Egebjerg (2012) is to "observe the production management of filmmaking through the optics of the construction site". The perception that "professional movie productions far better meet their goals for time, budget and quality than construction productions do" (p. 2) is supported by industry reports and by interviews of top managers, researchers, business organizations and other professionals in both industries in Denmark and the United States. The method of the thesis is ethnographical observations on Danish and USA large studio movie sets and Danish construction sites, as well as qualitative interviews and literature studies. She finds that planning in the production (shooting) phase of filmmaking is done through a very detailed, and yet flexible planning system. She further finds that film crews are very focused on the overall quality goals of the project and that, even though they are experts with different tasks and responsibilities, they work together in a flexible and focused way that ensures the overall flow and quality of the shooting process. She concludes by recommending that construction apply a detailed yet flexible planning and control approach similar to that of filmmaking.

Persse's approach to learning from filmmaking is to go through four of the five phases of the project model of filmmaking (development, preproduction, production, post-production), looking for similarities between filmmaking and software development and identifying takeaways for software development. The book is relevant for the present paper because it also attempts to learn from filmmaking and because it gives a good introduction to the Hollywood system and filmmaking in general.

DESIGN SCIENCE RESEARCH METHODOLOGY

The term "design science" originated with Herbert Simon's *The Sciences of the Artificial* (Simon, 1969). The origin of design science research can be traced to the paper by Kasanen, et al. (1993) in which the authors propose to focus management accounting research on the design of more effective accounting systems. In this, they followed Johnson and Kaplan's (1987) claim that management accounting had become increasingly irrelevant to practice. The methodology was subsequently applied by Van Aken (2004) more broadly to management as such, proposing that management research be regarded as a design science alongside medicine and engineering, as distinct from an exclusively explanatory science like physics and chemistry.

The difference between design science and design science research is that the latter must not only solve a practical problem but also make a contribution to theoretical knowledge. The practical problem to be solved in this research is improving the performance of both filmmaking and construction projects by transferring knowledge between them. One contribution to knowledge is the proposed hypothesis; namely, that the future state proposed by advocates of lean construction already exists in filmmaking.

ARGUMENTS FOR THE HYPOTHESIS

In this section, we present comparisons of selected aspects of filmmaking and construction in support of our hypothesis. A comprehensive comparison of filmmaking and construction is deferred to future publications.

A FRAMEWORK FOR COMPARING

In this paper, filmmaking and construction are compared using the three elements shown in Figure 1: commercial terms/contracting, organizational structure & culture, and operating system. Commercial terms are agreements between participating organizations or individuals regarding who will do what work for what compensation and with what risk. This element also includes the criteria for contract award. Organization includes both structure and culture.

The operating system consists of the fundamental principles and methods by which the project will be managed.

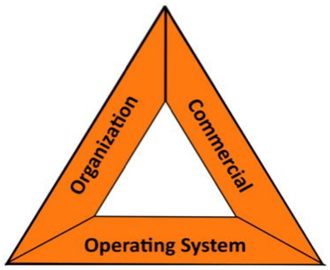

Figure 1: The Basic Elements in Projects (adapted from Thomsen, et al. 2009).

Comparisons of filmmaking, traditional construction, and lean construction regarding these three elements is shown in Table I.

Table 1: Comparison of Filmmaking with Traditional and Lean Construction

	Filmmaking	**Traditional Construction**	**Lean Construction**
Contracting	Select by qualifications, pay negotiated rates, risk is borne by the entities best able to both manage and mitigate the risk	Select by low bid, pay fixed price for fixed work scope, risk borne primarily by the performers	Select by qualifications, pay negotiated rates, risk is borne by the entities best able to both manage and mitigate the risk
Project Culture	Collaborative but not consensus decision making, high team identification with project objectives	Command and control, low team identification with project objectives	Collaborative but not consensus decision making, high team identification with project objectives
Operating System	Management by Means and Results	Management by Results	Management by Means and Results

LEAN CONSTRUCTION'S FUTURE STATE VISION FOR ITS PROJECTS

All projects can be located on a continuum ranging between simple/certain and complex/uncertain. Traditional commercial terms in construction depend on a fixed relationship between work scope and compensation--deliver specific scope of work X in exchange for Y amount of money. As projects become more complex and uncertain, that fixed relationship is increasingly difficult to maintain, and eventually becomes an obstacle to project success because it discourages the cross-discipline/cross-trade innovations needed to meet the challenges of complex and uncertain projects.

Contracts can also be located on a continuum, in this case between the fully transactional and the fully relational. Although all contracts are some blend of both (MacNeil 1980), traditional construction's reliance on fixity of work scope results in largely transactional contracts, which reduce the agreement to an exchange of this for that. More complex and uncertain projects need contracts that are largely relational; contracts that engage a team of professionals to help deliver a challenging project. The future state vision for lean construction projects is shown in Figure 2.

Construction projects have traditionally formed their teams by inviting designers and negotiating their compensation, and by competitively bidding for general contractors, who in turn competitively bid for subcontractors. Everyone has their own financial situation to protect, so opportunities for improving project performance by shifting scope and revenues across organizational and contractual boundaries is usually resisted.

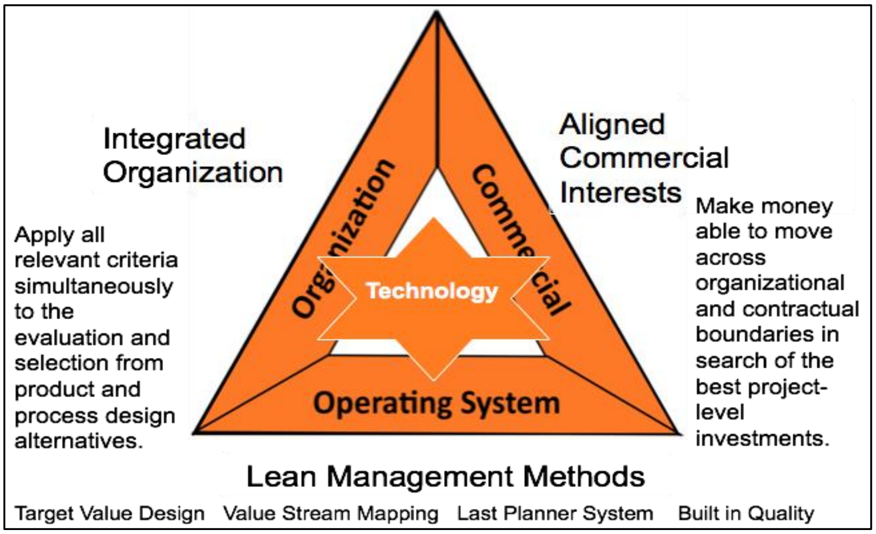

Figure 2: Integrated Lean Project Delivery

Lean construction, like filmmaking, awards contracts based on qualifications and does not try to achieve cost certainty by pushing cost risk onto providers. Indeed, in the various project delivery processes that go by the name of "integrated project delivery", risks are shared, but consistent with the principle that risk should be borne by the entity best able to both manage and mitigate the risk, and also best able to absorb risk events should they occur.

Turning now to project organization, traditional forms of organizing construction projects might be called 'sequential processing'; i.e., each player is brought onto the project only when they are to perform their specific scope of work. The design of the building limits alternatives for construction methods, but the constructors do not participate in the design phase of the project, and designers do not get feedback about the buildability of their designs because they are not present in the construction phase.

This engagement of specialists only when their specific work scope is to be performed, together with traditional contracting practices, results in a command and control approach to project governance, which tends to stifle collaboration and innovation. Filmmaking and lean construction differ from traditional construction in this dimension of organizational culture (less so in structure). Project organizations require hierarchies that allocate decision-making power, but that power can be misused. A better use of power is to seek input before declaring a decision, and to recognize when taking the lead in a problematic situation may better be done by someone other than the person in charge (Weick and Sutcliffe 2011).

Let's now consider the management system for construction projects. Koskela and Howell (2002) argue that the traditional system is obsolete. They criticize decomposition of tasks, management focused on push as opposed to pull, restriction of execution to dispatching, and the thermostat model of controlling.

Decomposition of tasks rests on the assumption that the various scopes of work to be performed are independent of one another except as regards sequencing. Risk shifting makes proactive management of production impossible. From these two premises, it follows that project management is understood as the management of contracts, as distinct from the management of production (designing and making things).

Pushing tasks into execution in accordance with the project schedule is counterposed to management by means; i.e., creating and maintaining the conditions for successful execution, which includes adapting plans to emergent circumstances.

Given these first two, it naturally follows that execution is understood as directing that specific tasks be done, with no consideration to the conditions required for successful execution of those tasks (dispatching).

And finally, the concept of control in traditional construction project management is exclusively reactive, and excludes proactive control. Project controls have the job of determining if the project is on course to meeting its objectives for safety, quality, time and cost. In traditional construction project management, doing what is needed to cause the project to meet its objectives is considered to be outside the realm of project management, which may bring pressure to bear on those executing the work (e.g., by threatening to exclude them from future projects), but does not otherwise get involved in production planning or execution.

The management system for Integrated Lean Project Delivery includes project controls, but also management by means. Its primary methods are target value design, value stream mapping, the Last Planner system, and Built in Quality. These apply to the entire project, consistent with organizational integration and aligned commercial interests. Target value design drives the project to deliver customer value within customer constraints for cost, time, and other conditions of satisfaction. Value stream mapping is used to improve the flow of information and materials through processes. The Last Planner system improves workflow reliability, which stabilizes the entire project. Built in Quality includes detecting deviations as close as possible to the source, taking corrective action to enable production to resume, and analyzing deviations in the search for countermeasures to prevent reoccurrence.

Developments in information technology, including Building Information Modelling (BIM) are changing the design process into a virtual assembling of components and systems. This assembly process requires the collaboration of design and construction specialists; collaboration that is inconsistent with the sequential processing of traditional construction.

Relatively recently, lean management methods have been coupled with selection of project team members based on qualifications, the assumption of cost risk by Buyers or Design-Builders, organizational integration, bringing downstream players into upstream processes, and upstream players into downstream processes (Thomsen, et al. 2009). This combination, which resembles the normal situation in filmmaking, has proven successful in motivating attention to reputation and promoting collaboration, including moving money across contractual boundaries in search of the best project-level investment (Thomsen, et al. 2009; Conwell 2012).

HOW FILM PROJECTS COMPARE

In this section, arguments will be made in support of the following claims:

- Film projects are highly uncertain and complex
- Film projects align commercial interests of participants in a way that facilitates collaboration and invention

- Film projects involve key players across multiple project phases; i.e., integrate organizationally
- The culture of film projects is collaborative but intensely driven to achieve project objectives

Film projects tend to be highly uncertain and complex. They require coordination of many elements, with a high degree of probability that something unexpected will occur. This complexity is evident in the Pre-production phase, which includes organizing cinematography, electricians, scenography, make-up, costume, sound departments, casting companies, location scouts, props, stuntmen, special effects, animal trainers, gardeners, and much, much more.

Film projects form their teams largely by inviting the key players and negotiating their compensation. On the large feature film projects studied in this research, cost risk is borne directly by the company responsible for producing the film. Selection of team members is based on qualifications and reputation, which puts a premium on creating and maintaining those credentials. That, coupled with the absence of cost risk, creates conditions that promote collaboration between ‘investors’ and ‘creators’.

In film projects, key players participate in multiple project phases, thereby achieving the organizational integration needed both to promote learning and to provide constancy of purpose. Such key players include the producer(s), director, production manager(s), cinematographer, and others, depending on the project. The presence of these key players through all phases bridges between designing and making--but also bridges across hierarchy between the different professional groups. Note that, just as in construction, other specialists than these ‘key players’ may participate in the project only when their specific tasks are to be performed; e.g., actors coming and going to the set, stuntmen, extras, etc.

The culture of film projects is highly collaborative yet intensely driven to achieve project objectives. Once filming starts, the process is re-designed on a daily basis in an agile coordination with inevitable changes like weather conditions, illness in the main cast, accidents, etc.; but only inside the overall budget and schedule.

CONCLUSIONS

This section consists of a summary of findings from the arguments above, limitations of this research, and recommendations for future research.

Arguments for the following eleven statements have been made in previous sections of this paper. The statements describe both the lean vision for construction project management and current filmmaking practice, and thus support the hypothesis: *the future state proposed by advocates of lean construction already exists in filmmaking*.

1. The entire team is aligned to the project goals.
2. Risk is borne by the parties best able to mitigate occurrence of risk events and best able to bear the burden if risk events should occur.
3. Participants in the team are assigned based on skills, relations and previous work.
4. Resources (time and money) can be reallocated between tasks in order to increase value and flow (keeping the budget and end date constant)
5. Downstream players are involved upstream and upstream players downstream.
6. Top management are present, visible and actively involved.
7. The project is managed both through contracts and through direct management of production.

8. Continuous update of project status and forecast are integral parts of the planning concept.
9. Plans get more detailed the closer one gets to executing planned tasks.
10. As the plan gets more detailed, preconditions are established and constraints removed in an on-going dialogue.
11. The plans are detailed, and still have a level of agility.

LIMITATIONS OF THIS RESEARCH

The objective of this paper is to provide a plausible argument for the hypothesis: *the future state proposed by advocates of lean construction already exists in filmmaking*. The authors relied upon previously published descriptions and their own experience in the construction or filmmaking industries. No new descriptive research is presented. More testing of the hypothesis is required, including further examination of differences between the two project production systems, in addition to the similarities stressed in this paper.

RECOMMENDATIONS FOR FUTURE RESEARCH

One very interesting characteristic of filmmaking is the high degree of commitment by project team members to achieving project objectives. That appears to be in part the result of selecting team members based on qualifications, not low price. While advanced lean construction practice also involves qualification-based selection, it is not yet clear what will happen industry-wide as lean construction is taken up more broadly. Filmmaking may offer a way to see lean construction's future.

The interplay of cost risk and risk of damaging reputation is one strong thread in this future research. Another is the choice of negative vs. positive incentives in the design of commercial terms. The differences between construction and filmmaking also need to be further explored; e.g., differences in business contexts.

We invite other scholars and practitioners to join us in this research.

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THREE-LEVEL METHOD OF TAKT PLANNING AND TAKT CONTROL – A NEW APPROACH FOR DESIGNING PRODUCTION SYSTEMS IN CONSTRUCTION

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

ABSTRACT

Due to the individualized design and construction of buildings, recurring processes are often not recognized. Because of this, potential improvements are not applied to future projects. With the use of Takt Planning and Takt Control, an effective method exists for identifying recurring processes and thereby adding stability to the construction process. Until now the focus has been on the optimization of the trade sequences during project execution whereby mostly one particular construction phase is considered.

This paper describes a newly developed method for designing a Takt Planning and Takt Control system. This method is based on a model with a three level hierarchy to be used for defining Takt and the related workspace.

The effectiveness of the method developed was analysed in a case study in a large-scale project. With application of this method, the building phases could be interlinked and the construction time could be reduced from the original eleven months down to five months. Additionally it could be shown that the division into three levels provides managers with the necessary transparency, helps them to make better decisions and to simplify controlling of a construction project. Furthermore, the method enables an improvement in the interlinking of construction phases with the operating phase of a building. The implementation of standardization across different levels allows a continuous improvement of processes from a multi-project perspective. With the help of the method used, the project won the “German Project Management Award 2015”. Building on the results presented in this paper, the method and its effectiveness need to be validated in further construction projects.

KEYWORDS

Production system design, Takt planning and takt control, systematic approach, generic structure.

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INTRODUCTION

During process planning for construction projects, knowledge gained from earlier projects is rarely integrated into future project structures. Generally there is no generic structure that can be applied to multiple projects. This means the quality of processes and relevant data cannot be compared across different projects. The reason is that every construction project is completed on an individual basis. The potential offered by higher levels of standardization of process structures thereby remains unrealized.

During projects, construction phases are only optimized individually, also known as the "over the wall" approach (Ehrlenspiel 1999). After optimization is completed within one construction phase, information is passed to the next phased over "invisible walls". Networked and structured communication is not part of planning the project meaning that the interfaces between different construction phases are first defined during project execution. Therefore a transparent value-creation process binding to all project participants does not exist – the foundations for effectively leading performance delivery are missing.

Bulhões et al. (2005) consider work planning on multiple levels. A central element is value stream management, which despite being able to optimize and individual project to meet its goals, does not allow a generic approach able to be applied at a multi-project level. Takt Planning is mentioned, however is not a part of the systematic approach. In their approach to Takt Planning Frandson et al. (2013) list six steps leading to a Takted production plan. Within each level variations and associated buffer times are planned. The approaches of Takt Control and optimization across multiple construction phases are not part of the method.

The research to date shows that there is a need for a new method for designing a Takt Planning and Management System on the basis of a generic and systematic project structure for construction projects.

This contribution describes further development of Takt Planning and Takt Control Systems resulting in the integration of collaborative elements. The three-level method developed here based on a three-level hierarchy model. Every level is structured to be built upon the previous level in terms of spatial and time factors. The advancement offered to construction projects is found in the level of detail possible for project planning. The significance is the ability for independent decision-making and collaboration between project participants at the relevant levels at any time without affecting the client's wishes. The method allows for greater transparency in the construction process for all parties. Furthermore data from individual construction processes can be compared with the same processes from other projects. This allows continuous improvements across all projects.

THE THREE LEVEL METHOD FOR TAKT PLANNING AND TAKT CONTROL

FOUNDATIONS

The theoretical foundations of the method originate in network theory as well as action regulation theory.

Action regulation theory describes a network and its participants. Known proponents of this theory are Walter Volpert and Winfried Hacker. According to Volpert (1994) actions can be broken down from their global objectives hierarchically, and built up again to assess if objectives have been met. The definition of levels allows assigning of different levels of accountability. Hacker (1973) differentiates between the steps of planning, execution, controlling execution. This sequence of action is similar to the PDCA cycle of lean theory.

Three levels are often used when allocating levels of accountability (Best and Weth 2005). This allows the most efficient knowledge transfer between all parties. The simplified standardization of products and processes improves existing systems.
Network theory also describes a system with participants divided across three levels: at the macro level the environment of the production system and its associated relationships can be considered from a multi-project perspective. The middle level shows all resource and information flows within the organization and its internal groups. The micro level, with the highest level of detail, shows individual roles, competencies, workstations and dependencies between roles (Zundel 2013; Sultanow 2010).

THE NEW METHOD

In stationary industry processes the product (object) flows between workstations with the labour (subject). Conversely, in the construction industry the labour (subject) and its services flow through the construction project (object) (Ballard und Howell 1998; Friedrich et al. 2013). Therefore labour in the construction industry must be completed at a specific time in a specific place. In construction processes time and space are linked and co-dependent. The new method divides these into three levels: the 'macro level', 'norm level' and 'micro level'.

MACRO LEVEL: PROCESS ANALYSIS

The macro level incorporates preparing a milestone plan for the different functional areas. The objective is to compete a systematic process analysis at an early stage to define priorities from the perspective of value to the customer. This places greater value on collaboration between project participants, and those at interface points. Clashes can be detected and dependencies defined. The result is a common vision for completing the future construction project.

Building upon this, the interface points and sequencing of works for the construction phases can be defined and optimized. Existing data from earlier projects can be utilized in different functional areas. Through escaping time and product related project constraints, a generic project structure emerges.

NORM LEVEL: TAKT PLANNING

At the norm level Takt planning reflects the customer's spatial prioritization. The value-adding process is therefore defined according to customer (user) requirements across all levels of the hierarchy. The time and spatial divisions are built up according to the macro level structure.

To be able to plan an equalized and stable construction process, the functional areas must be divided into standard space units (SSU). Under the defined work sequence these cannot be further subdivided, and can be finished independent of one another. Through division into small spatial units, there is a detailed dataset as a basis for harmonizing performance factors. Moreover different combinations of SSUs into different Takt areas are possible. These Takt areas are to be defined according to the customer's spatial prioritization.

For every work package in the work sequence, the process steps involved are identified and the work required is documented. As shown in Figure 1 the three levers of subjects, objects and machines can be used for harmonizing workloads (Engström 1987).

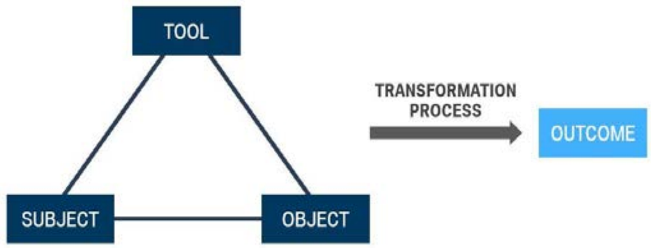

Figure 1: Factors influencing the transformation process (according to Engström 1987)

- Subjects are the workers: by defining the number of people working in each trade, the workloads can be equalized.
- Objects are the SSUs: through combining SSUs into Takt
- The type and number of machines also influences the workload.

The teams for completing the individual work packages are metaphorically grouped as wagons of a work train passing through the different Takt areas. The sequence of construction follows the spatial prioritization of the Takt areas, and therefore the customer's requirements. The generic elements of the macro and micro levels are fit to an individual project.

The Takt plan prepared in a production layout and named "WIP" by Faloughi et al. (2015) includes the dimensions of space and time. The definition of parameters leads to replicable work packages and early stage planning of material flows and machine use. Using workable backlogs (Sepannen 2014; Hamzeh 2008) for non-replicable work packages in prioritized surfaces is also possible. Knowledge gained and variations at the norm level are directly transferable to the macro level.

MICRO LEVEL: TAKT CONTROLLING

The micro level encompasses the detailing of the process packages of the norm level and management during execution of construction. The generic connection to the macro level remains through the work steps of the process packages.

Work steps for Takt areas are taken from the process packages at the norm level. They are planned according to the Takt timeframe within the framework of a collaborative procedure between the project manager and subcontractors. Managing execution of construction occurs through daily short-cycled Takt status meetings lasting approximately 15 minutes. All site workers thereby meet with the accountable foreman. These meetings are inspired by shopfloor management of the stationary industries (Hofacker et al. 2010). For purposes of visualization and documentation, information is gathered during status meetings and recorded on a takt control board.

The Takt status meetings and takt control board are made up of two essential parts: firstly documentation of the actual status. Secondly the resultant measures to fulfil the requirements of the norm level.

Overview of the three-level method

Figure 2 summarizes the three hierarchical levels, which show the different levels of detail from the perspective of value to the customer. The components of the micro and macro levels are project-independent and therefore suited for application to different projects. The three-level method developed here is a flexible system. The knowledge gained at the micro level is automatically transferred to the norm level, and will influence planning in future. By harmonizing workloads, the norm level can react to findings at the micro level.

The following lists significant points defining the components of the developed three-level method:

- Process package: defined at the macro level and part of the process chain of the sequence of works of a particular functional area.
- Process plan: describes the macro level and its milestones and functional areas
- Work package: defines the works, which can be completed within each Takt and Takt area at the norm level. It is compiled during harmonization.
- Takt plan: is a structured construction plan with a complete overview of the construction process according to the spatial construction and time Takt.
- SSU (Standard space unit): is a small spatial and independent unit according to structural and manufacturing characteristics.
- Performance factor: is the average needed time for one work step.
- Work step: defined at the micro level for every SSU. They are allocated a performance factor.
- Dashboard/Takt Control board: incorporates the short-cycled inspection of building progress and operations at the location of value creation to ensure the takted construction process is followed.

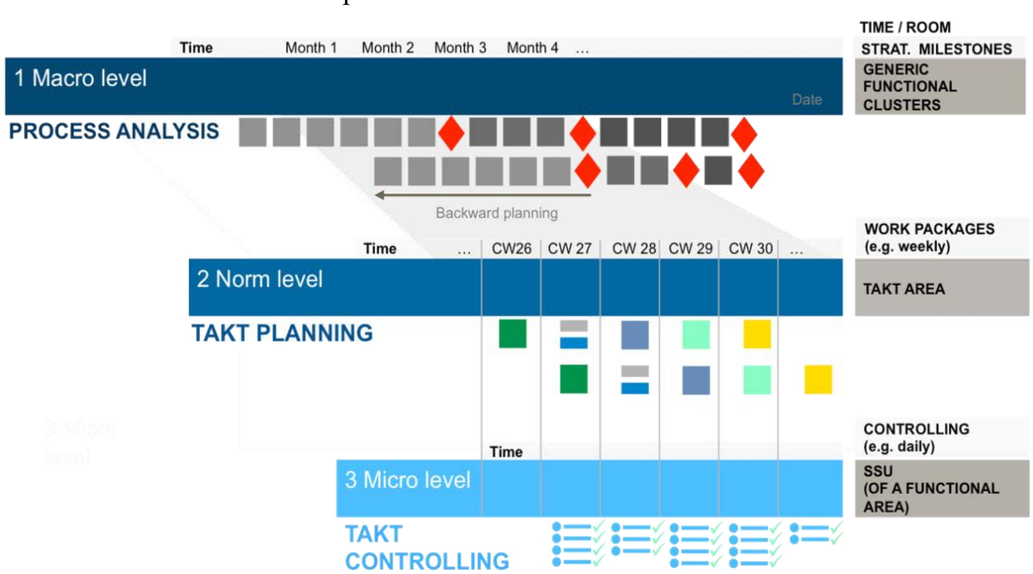

Figure 2: Overview of the three-level method

The effectiveness of the three-level method will be analyzed within the framework of a large-scale Greenfield construction project carried out by BMW AG. The building serves as a facility for storing parts, and their assembly into vehicles.

APPLICATION OF THE NEW METHOD ON A CASE EXAMPLE

KEY FACTS OF THE PROJECT BMW BRAZIL

The following lists the main actors and frame of reference for the project:

- Location: Joinville Region, Brazil
- Planned production capacity: 30,000 vehicles / year, 1,300 new jobs (Bimmertoday 2012)
- Project Size: Total Area 1.5 million sqm, 500.000 sqm surface area (Bimmertoday 2012)
- Project timeline: December 2012 – September 2014 (22 months total); with six months for execution of construction for the following case example
- BMW’s organizational structure comprised of a project leader, multiple project managers and external project controllers
- As end-user, BMW AG produces vehicles on the surface area. After handover of the building the end-user installed production facilities.
- The general contractor Perville Engenharia e Empreendimentos S.A is a multidisciplinary engineering team (comprising a project manager, project controller, specialist engineers, HS&E, purchasers and subcontractors).

MAKRO LEVEL: PROCESS ANALYSIS

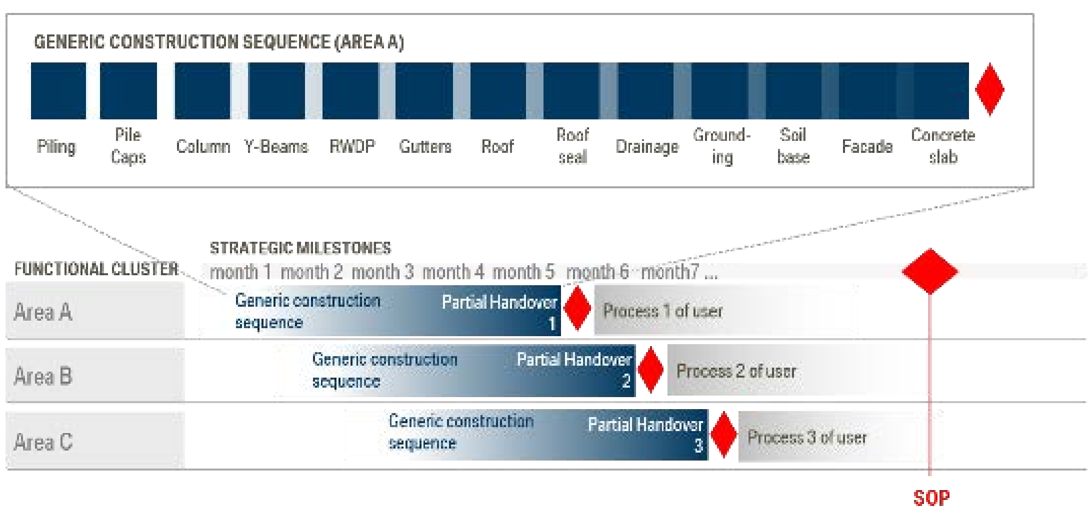

Figure 3: Milestone plan at the macro level with a generic sequence of works

In the case study, preparing the work sequence for the installation and construction processes began from “SOP” (Start of Production). The sequencing for the shell construction and milestones of the construction project are shown in Figure 3. By showing the nature and complexity of the process, individual spatial areas within the production hall can be identified and prioritized.

After the process analysis, the structure was divided into three areas according to the perspective of the customer wishes (Area A, Area B (B1 + B2), Area C) (see Figure 4). For partial handover of building areas the following conditions had to be met: the façade must be predominantly closed-in, the roof watertight and the floor prepared for assembly works.

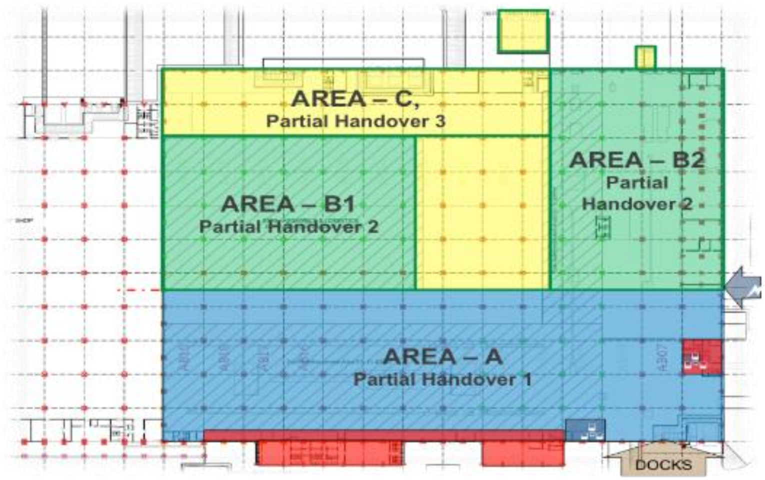

Figure 4: Categorization of customer’s spatial area prioritization

NORM LEVEL: TAKT PLANNING

Trade Sequence	SSU	Performance factor / SSU	Man-power	Duration / SSU	Takt area	Performance factor (total)	Levelling (Takt time = 5 days)
Piling	5 piece	5*160 min.	4	40 min.	60 pieces (with 2 Takt areas)	5 days	W1
Pile Caps	2 piece	2*480 min.	4	120 min.	13 pieces	3.25 days	W2
Column	1 piece	1200 min.	5	240 min.	7 pieces	3.5 days	W3
Y-Beams	1 piece	800 min.	5	160 min.	5 pieces	1.67 days	W4
RWDP	1 piece	320 min.	2	160 min.	6 pieces	2 days	
Flat gutters	2 piece	2*80 min.	5	16 min.	30 pieces	1 day	
Gutters	3 piece	3*300 min.	5	60 min.	16 pieces	2 days	
Roof	1 grid	3840 min.	8	480 min.	5 grids	5 days	W5
Roof seal	1 grid	1920 min.	4	480 min.	5 grids	5 days	W6
Drainage	18 m	18*149.33 min.	7	21.33 min.	90 m	4 days	
Grounding	18 m	18*10.67 min.	2	5.33 min.	90 m	1 day	
Soil base	324 m^2	324*10.37 min.	7	1.48 min.	1.620 m^2	5 days	W7
Facade	2 piece	2*240 min.	5	48 min.	10 pieces	1 day	
Concrete	360 m^2	360*20 min.	15	1.33 min.	1800 m^2	5 days	W8

Figure 5: Example of a harmonization table

For developing the Takt plan (production plan) a SSU was defined for all functional areas during shell construction. Furthermore by arranging the performance factors to the individual process packages, the work sequence was harmonized by balancing the size of teams and machine capacities. The result was one Takt made up of five work stages, and one Takt area made up of six SSUs. When defining the Takt areas, safety regulations had to be considered meaning that mobile cranes could not be used in adjacent SSUs. The work packages making up one Takt and Takt area together comprise one "wagon". In the following harmonization table, the wagons studied are labelled as W1, W2, W3 etc. (Figure 5).

One work train was calculated to contain 28 Takt areas. These, and one SSU are shown in Figure 6. Also figure 6 shows the completed Takt plan. After implementation less Takts were needed after adjusting to the norm level. For example, construction management changed the workload from five to six Y-beams per Takt area. The Takt plan also served as the basis of communication with external partners.

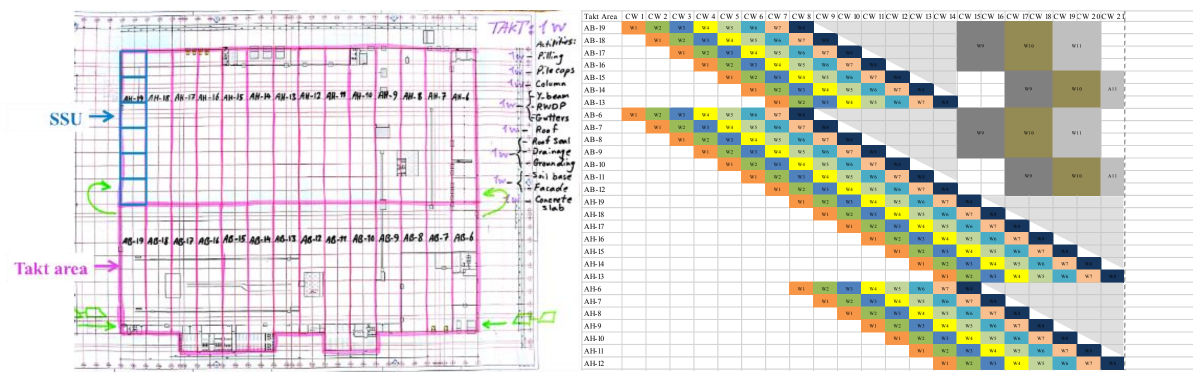

Figure 6: Defined Takt areas with SSUs and the Takt plan

MICRO LEVEL: TAKT CONTROLLING

Figure 8: Images of Takt meetings and dashboard

The micro level divides the work packages from the norm level into detailed working steps. The contractors executing construction cooperatively plan these working steps for the applicable Takt from the norm level.

As shown in Figure 8, the current and three upcoming Takts are visualized on the dashboard at the norm level. During daily Takt meetings construction progress is documented on the dashboard at micro level

RESULTS

In the case study using the three-level method generated generic processes, which can be reused in future projects. Moreover the standardization across the three levels results in continuous improvement.

Construction phases were determined in a commonly optimized flow according to the client's requirements. A side effect was that critical spatial areas such as Area could be handed over earlier as it was prioritized in an early stage of planning (see Figure 4). Dividing into three levels showed an improved visualization of the overall construction process. Both decision making for the project team and controlling the construction process were simplified. This meant no delays were recorded.

Using modular prefabrication, collaboration between PerVille and BMW, as well as Takt planning and Takt Control, allowed the construction time in the case study to be reduced by five months.

The project described in this paper was awarded the "German Project Management Award 2015".

Based on the results of this paper, the method and its effectiveness should be verified in future construction projects.

CONCLUSIONS

The three-level method described in this paper shows a system that can be used generically and from a multi-level perspective. It is possible to use work sequences at the macro level and performance factors of individual work steps at the micro level in multiple ways. The norm Takt comprises the total added value of the construction site making them transparent and available to all project participants. Processes are adjusted to a concrete project through the top-down approach of the macro level, and the bottom-up approach of the micro level. The macro, norm, and micro levels divide the project both in terms of space and time, so that the customer's requirements can be structured and followed at all levels. Interfaces between the construction phases can be transparently stated, and optimized according to the customer's batch size.

This case study shows that data for further development in subsequent projects is possible, that it is possible to commonly optimize according to the customer's requirements and that the construction process becomes more efficient.

Further development of the three-level method would be based on data from various construction projects. These data could be used for deviations from standardizations, which through continuous improvement can generate noticeable efficiencies in construction processes.

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TAKT TIME PLANNING IN CRUISE SHIP CABIN REFURBISHMENT: LESSONS FOR LEAN CONSTRUCTION

Aleksi Heinonen[1], Olli Seppänen[2]

ABSTRACT

Takt time planning has recently received a lot of attention in lean construction community. However, very few empirical results have been reported. This paper presents a takt time planning case study from a closely related industry, cruise ship cabin refurbishment. The results of lean implementation in the case company have been very good, including productivity increase to 380% of baseline, WIP decrease of 99%, quality defect decrease of 99% and project lead time reduction of 73%. The paper reviews the process used and compares and contrasts the takt time method implemented by case company and the process proposed for construction in previous lean construction conferences. The implemented takt time method was found to be similar to the method proposed in previous lean construction conferences but it includes several additional process steps such as explicitly considering material logistics and garbage collection and real-time data collection. The main differences between project types are in logistics setup and business drivers impacting desire to cut lead time over improving resource efficiency. Interestingly, cycle time reduction achieved both goals in the case company. The contribution of this paper is to show the benefits of takt time planning and to propose additional components to takt time planning process.

KEYWORDS

Takt time planning, logistics, flow, work in progress

INTRODUCTION

Takt time planning has its origins in lean manufacturing based on setting production rates to match the demand rate (e.g., Hopp and Spearman, 2008). The theory has been adapted for construction by Frandson and Tommelein (2014) but there are several earlier practical implementations (e.g. Court et al. 2005; Court et al. 2006). Takt time planning has a lot of similarities with Location Based Management System (LBMS, see comparison of the two methods in Frandson, Seppänen and Tommelein, 2015). Some empirical results have been reported for LBMS (for example, Seppänen 2009) but so far few empirical results have been reported for takt time planning. LBMS empirical results are focussed on metrics such as project duration, number of

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production problems, production rates and productivity but ignore important lean metrics of Work-in-Progress and cycle time.

In this paper, we will describe a case study of a cruise ship cabin refurbishment contractor, who have implemented takt time planning in a project type very similar to construction and have gained impressive results. The process of the company is described in detail and numerical results of key lean performance indicators are presented. Finally, the process is compared and contrasted with the processes of Takt time planning method proposed for construction and implications for lean construction are discussed.

CASE STUDY

CASE COMPANY

I.S Mäkinen Oy is a Finnish turnkey contractor specialized in cruise ship cabin refurbishment. Typical projects are executed in two to four weeks for a project of 300 – 1,500 cabins with a workforce of 100-280 technicians. Cabin refurbishments contracts are typically from three to ten million USD. Cycle time is critical because the opportunity cost for the Owner of one day of docking can be one or two million USD, depending on the time of year, location and vessel class. Because of huge opportunity costs, there has been strong external pressure for I.S Mäkinen to decrease cycle times or lose business. This has served as a strong motivator to radically improve processes by implementing lean and takt time planning. I.S Mäkinen started Lean development in 2012 and the results have been extremely good.

CRUISE SHIP CABIN REFURBISHMENT PROJECTS

A typical cabin refurbishment project scope includes changing the carpet, TV and soft goods but extensive scopes can include changing everything from lighting to wall finishes. Because of high opportunity costs to the owner, there are late delivery penalties for the contractor of 1.5% of contract value per day, up to a maximum of five days (7.5%). The damage of delay to the Owner is far greater than the maximum late delivery penalty which makes the relationship damage more important than money. Cost of labor is around 30% of total project cost in the industry, so any improvements in productivity can result in significant project cost decreases.

Before implementation of lean, batch processing was used. Materials were moved in and out of ship in large batches using a huge crane. Workers started cabins as soon as possible and the production rates were not synchronized. To avoid penalties, overtime in the final stages of each project was common, accounting for 10-20% of project hours. Typical results of the traditional process included finishing a batch of 35 cabins each day. A good contractor would finish the project on time with a few hundred minor quality punchlist items, ranging from wrong color of silicon in the bathroom to minor carpet cutting errors or a missing ottoman in the cabin.

Problems of the traditional way of mass refurbishment have been low production, difficulty of managing quality, bad visibility of project progress and excessive space requirements.

IMPLEMENTED LEAN PROCESS

The Lean process setup is very similar to a production line, where products stay in place and the workers move. This line is called a construction train. The work stations are called wagons, where multiple people work. Foreman is called a train driver. The production system design includes three steps:

Defining standard work flow within construction train

Defining logistics

Defining management roles and responsibilities.

These steps are elaborated below.

Defining Standard Work Flow Within Construction Train

Standard work flow definition starts with customer's project specification which includes the scope of work within each cabin. Each scope line item is then broken down into a set of tasks, for example demolition, smoothening of surfaces, painting or outfitting. Each task gets a workload value in man minutes per cabin. It could also be man minutes per item but it is more intuitive to think in terms of whole cabins. Ideally, the values should come from a library of measurements from previous projects. However, when the project specification includes items whose resource loads are difficult to derive from previous measurements, they are at least educated guesses, which can be based on mock-up cabin experience.

Cabin type and scope can vary. This variance can be dealt with multiple ways, depending on the frequency and amplitude of variance. If the frequency is small and amplitude moderate, for example accessible cabins for persons using wheelchairs are bigger and have more furniture and special devices, it may be best to use a separate task force to do these cabins completely outside of the takt schedule, or do only the additional work over standard cabin scope outside the takt schedule. If both frequency and amplitude are moderate or high, for example cabin suites compared to standard cabins, separate trains may be required or they can be scheduled last in the sequence with a longer takt time and different standard workflow.

Takt time is the time system has available to produce one cabin. It is calculated roughly as the time available per cabin:

[(project duration x net daily working time) – single unit lead time] / (number of cabins -1)

If the takt time becomes very small with this formula and the waste ratio of moving from cabin to cabin, compared to value adding time inside the cabin is unfavourable, i.e. with under 10 minute takt time, additional construction train may be added and the takt time doubled for each train.

Single unit lead time will get an accurate value later in the process but at this point it is possible to get an estimate of minimum single unit lead time by dividing the total man minutes by crew size per cabin, and adding the drying times on the critical path (i.e. levelling h + waterstop h + tiling h + grouting h]. The optimal crew size per cabin is usually around 3 for standard cabins with one person working in the wet unit and two on living unit side. In reality, the optimal crew size varies for each task.

Tasks need to be organized by logical and resource dependencies before they can be bundled into wagons which are the standard sets of tasks repeated every takt time by the same crew. Optimal resources are now defined for the actual bundle of tasks. The combination of tasks needs to have a shorter lead time (Sum of tasks' resource loads in man minutes / headcount) than the takt time with some buffer to cover for variance. The size of this buffer is an optimization problem balancing resource efficiency and flow stability similar to any production environment.

Drying time may require some empty wagons, where no work is done. Night time drying can be utilized only if the drying time is required to be longer than gross daily working time, to be valid for every takt of the day. This limitation can cause a false temptation towards bigger batches, where night time drying time is easier to utilize. Drying time must be smaller than the number of empty wagons multiplied by takt time. If the number of empty wagons is more than the daily production rate, the night time length can be included in the calculation. Figure 1 shows a takt time schedule of 15 wagons for one day.

Train:	1		**TD:**	Mr. XY		**SM:**	Mr Paul Deschenes			**Date:**	4.4.16	**Version**	21.3.16	11:53			**Takt time**
Start time	7:00 AM	**End time:**	7:20 PM														**0:25**
Date	**Time Star**	Wagon 1	Wagon 2	Wagon 3	Wagon 4	Wagon 5	Wagon 6	Wagon 7	Wagon 8	Wagon 9	Wagon 10	Wagon 11	Wagon 12	Wagon 13	Wagon 14	Wagon 15	Comments
4.4.2016 7:00		7056	7058	7060	7062	7064	7070	7072	7074	7076	7078	7080	7082	7084	7086	7088	
4.4.2016 7:25		7054	7056	7058	7060	7062	7064	7070	7072	7074	7076	7078	7080	7082	7084	7086	
4.4.2016 7:50		7048	7054	7056	7058	7060	7062	7064	7070	7072	7074	7076	7078	7080	7082	7084	
4.4.2016 8:15		7046	7048	7054	7056	7058	7060	7062	7064	7070	7072	7074	7076	7078	7080	7082	
4.4.2016 8:40		7044	7046	7048	7054	7056	7058	7060	7062	7064	7070	7072	7074	7076	7078	7080	
BREAK 09:05 - 09:20																	
4.4.2016 9:20		7042	7044	7046	7048	7054	7056	7058	7060	7062	7064	7070	7072	7074	7076	7078	
4.4.2016 9:45		7038	7042	7044	7046	7048	7054	7056	7058	7060	7062	7064	7070	7072	7074	7076	
4.4.2016 10:10		7036	7038	7042	7044	7046	7048	7054	7056	7058	7060	7062	7064	7070	7072	7074	
4.4.2016 10:35		7034	7036	7038	7042	7044	7046	7048	7054	7056	7058	7060	7062	7064	7070	7072	
4.4.2016 11:00		7032	7034	7036	7038	7042	7044	7046	7048	7054	7056	7058	7060	7062	7064	7070	
BREAK 11:25 - 12:10																	
4.4.2016 12:10		7030	7032	7034	7036	7038	7042	7044	7046	7048	7054	7056	7058	7060	7062	7064	
4.4.2016 12:35		7028	7030	7032	7034	7036	7038	7042	7044	7046	7048	7054	7056	7058	7060	7062	
4.4.2016 13:00		7026	7028	7030	7032	7034	7036	7038	7042	7044	7046	7048	7054	7056	7058	7060	
4.4.2016 13:25		7024	7026	7028	7030	7032	7034	7036	7038	7042	7044	7046	7048	7054	7056	7058	
4.4.2016 13:50		7022	7024	7026	7028	7030	7032	7034	7036	7038	7042	7044	7046	7048	7054	7056	
BREAK 14:15 - 14:30																	
4.4.2016 14:30		7020	7022	7024	7026	7028	7030	7032	7034	7036	7038	7042	7044	7046	7048	7054	
4.4.2016 14:55		7018	7020	7022	7024	7026	7028	7030	7032	7034	7036	7038	7042	7044	7046	7048	
4.4.2016 15:20		7016	7018	7020	7022	7024	7026	7028	7030	7032	7034	7036	7038	7042	7044	7046	
4.4.2016 15:45		7014	7016	7018	7020	7022	7024	7026	7028	7030	7032	7034	7036	7038	7042	7044	
4.4.2016 16:10		7012	7014	7016	7018	7020	7022	7024	7026	7028	7030	7032	7034	7036	7038	7042	
4.4.2016 16:35		7010	7012	7014	7016	7018	7020	7022	7024	7026	7028	7030	7032	7034	7036	7038	
BREAK 17:00 - 17:15																	
4.4.2016 17:15		7008	7010	7012	7014	7016	7018	7020	7022	7024	7026	7028	7030	7032	7034	7036	
4.4.2016 17:40		7000	7008	7010	7012	7014	7016	7018	7020	7022	7024	7026	7028	7030	7032	7034	
4.4.2016 18:05		7001	7000	7008	7010	7012	7014	7016	7018	7020	7022	7024	7026	7028	7030	7032	
4.4.2016 18:30		7043	7001	7000	7008	7010	7012	7014	7016	7018	7020	7022	7024	7026	7028	7030	
4.4.2016 18:55		7040	7043	7001	7000	7008	7010	7012	7014	7016	7018	7020	7022	7024	7026	7028	
4.4.2016 19:20		7050	7040	7043	7001	7000	7008	7010	7012	7014	7016	7018	7020	7022	7024	7026	

Figure 1: Daily takt time schedule of 15 wagons. The takt time in this example is 25 minutes.

After the value adding work has been organized into wagons, the next step is to define material delivery and garbage collection points. If the takt time is very short compared to material delivery time accuracy, material delivery may also need to be an empty wagon where no work is done.

Defining logistics

Logistics planning process involves at least planning the material sequencing for long haul material shipment, material delivery routes off- and onboard and takt time scheduling for JIT deliveries. Ideally for efficiency, all material required for the project should be sequenced for one-piece flow in the first point of packing. This means packaging all the items needed for one cabin together so that they require minimum handling as late as possible on site. However, for logistics cost efficiency, bigger batches may optimize long haul logistic costs with better packaging ratio in order to require fewer sea containers and trucks. A good compromise is to ship long haul items in batches and to pick the materials to be delivered on board Just in Time outside the ship. If material picking is done on-board the ship, a lot of space is consumed and fire load is added on-board. Items are shipped in at least two containers to decrease the risk of losing a container for a few days, which sometimes happens on big shipyards.

One-piece flow and JIT deliveries require that materials are moved for the needs of one cabin, exactly when the material is needed, every takt time. Delivery trolleys are used to move materials onboard through the corridors. All routes of these trolleys need to go in the same direction to avoid passing on narrow ship corridors. Material delivery trolleys may be used for demolition garbage transportation, so it is convenient to design the logistical route so that it aligns with construction direction and material can be delivered just before picking up garbage. Rather than using the traditional huge crane to haul materials, it is better to use a flat gangway connecting off-board material handling point to ship’s service corridor so that material trolleys can flow in and out of ship on each takt time. Figure 2 shows a picture of a material trolley.

Figure 2. Material delivery trolley and sea containers in Singapore

Logistics flow may get interrupted by accidental power shutdowns, miscommunication between contractors etc. so some material delivery safety buffers are required as close to cabins as possible. They should be just large enough to cover the length of probable material delivery interruptions divided by takt time.

Materials get picked for one cabin each takt time, just enough in advance for delivery to the cabin. This advance time is calculated as delivery lead time rounded to the next takt time plus material buffers times takt time. Takt time schedule defines the entry and exit times of each wagon to each cabin and logistics scheduling. The spreadsheet gets heavy to update manually, so a parametric scheduling tool based on Excel, is used to automate takt time scheduling.

Management roles and responsibilities

Foremen are called train drivers. They oversee the wagons, ensuring that they follow construction direction, meet takt time and pass quality standards. It is the job of the train driver to call for countermeasures immediately if any one of these is at risk. The management focus shifts throughout the project. During production ramp-up, it is most important to ensure that everyone is having enough time to complete the set of tasks defined for the wagon in standard work flow. Deviations can be corrected by advising on correct working methods, changing or adding resources or changing tasks from a busy wagon to a less busy wagon, keeping in mind the dependencies between tasks and skills required by each task. If takt times are short (e.g. 15 minutes rather than 30 – 180 minutes), a co-driver is often appointed for each wagon focusing on quality and correct task execution methods. In these projects, the driver can have a “sergeant” profile with less construction experience and the co-driver can be an experienced construction foreman with ability to inspect quality and advise on working methods.

Logistics manager oversees the material flow to construction site and manages the logistics team, which is around 10-25% of the total workforce depending on the efficiency of the logistics setup. Logistics foremen oversee material picking and corridor logistics and participate in material handling.

Management meetings are held daily. Key Performance Indicators and their standards are defined for each project (i.e. quality, schedule, safety, tidiness, flow). They are measured continuously. Root causes of deviations are analysed immediately, countermeasures are defined and their results are monitored. Android tablets are used for recording wagons cycle times against takt time, and the data is analysed using Minitab statistical analysis for finding a better line balance.

ACHIEVED RESULTS

The results have been extremely good. Table 1 shows the comparison between Royal Caribbean Cruise Lines previous contractor in 2011 and Explorer of the Seas project in April 2015. Quality defects decreased to practically zero. I.S Makinen was able to deliver a zero punchlist project four times in a row in 2014-2015 which is an exceptional result in the industry. The good quality results from very short single cabin lead time. Final inspections can start within a few hours of construction start when completed cabins start to be delivered to the Owner. The Owner can give final instructions very early, ensuring that quality errors do not get repeated in all cabins. These instructions can range from silicone installation affecting the hygiene of the cabin or incorrect location of the toilet brush which can become a problem when multiplied by a 1,000 cabins.

Productivity increased to 380% of baseline compared to traditional process. This has resulted in a significant cost benefit, because the manpower cost accounts typically for 30% of total project cost in the industry. The productivity increase from I.S Makinen’s first takt time project in 2012 to the last one with similar scope (Explorer of the Seas) has been 57% but when the impacts of over-time work (no overtime in Explorer project, compared to 10-20% overtime in EN project), the productivity improvement has been closer to 80%.

WIP decreased by 99% which is the enabler for all other results. Traditionally, the first cabins were handed off to the Owner on the third to last day of a refurbishment project of 150 men working 12 h days, 7 days a week for three weeks, equalling 32,400 hours of work in process. Makinen refurbishment train delivers the first cabin to the Owner right after single unit lead time, which can be as small as three hours, and then the remaining cabins in takt time. 150 men working for three hours equals 450 hours of work-in-process.

Most importantly, project lead times reduced by 73%. The speed increased from 35 cabins a day in 2011 batch production to 62 cabins a day in the first one piece flow project in 2012 and to 126 on the last project with similar scope in 2015. This has increased the flow efficiency value to the Owner, enabling bigger scopes to be executed within standard dry docking schedule without need to increase out of service time.

DISCUSSION

COMPARISON OF PROJECT TYPES

Cruise ship cabin refurbishment is similar to building construction in many respects. The labor component and tasks performed are very similar to finishing trades in a construction project. Both project types have space as a critical resource and, in contrast with manufacturing, workers move through locations to perform work.

The differences are related to scope, duration and amount of activities, amount of subcontracting used, logistics setup, risk factors and variability, business case drivers and contractual requirements. In terms of scope and duration, building construction projects are multi-year projects (in contrast with a few weeks in this case study) and each trade can work in an area for a week or longer (in contrast with 15-180 minutes in this case study). The typical contractual set-up in building construction has a high percentage of the work delivered by specialized subcontractors whereas in the case study all employees were directly controlled by the case company. The building construction industry is very fragmented and there are a lot of operations with few opportunities for moving scope from one wagon to the next. In terms of logistics, building construction sites typically have much more space inside and subcontractors are often responsible for their own deliveries, making it hard to coordinate deliveries for individual locations. There are many uncertainty factors for building construction that do not exist in cruise ship refurbishment, for example weather risks and uncertainty related to design and requirements. Owners are not aggressively requiring lead time reductions, tending to settle for market cost and market duration, whereas the case company would have gone out of business unless they radically changed processes. Finally, the typical lump-sum environment decreases transparency and decreases the desire to improve productivity because the benefits of any process improvement can go to other parties in the process.

Table 1: Comparison of results between the previous contractor using traditional process, the first takt time project of Makinen and the last project with similar scope

Results	**2011** Baseline, previous contractor	**2012** First Makinen one piece flow project	**2015** Latest Makinen project with similar scope
Production rate (cabins/day)	35	62	126
Scope, proportional	100%	100%	130%
Manning (proportional)	100%	100%	140%
Resource efficiency (man hours per cabin)	100%	56%	26%

Quality	Hundreds of small to medium defects	Hundreds of small to medium defects	No claims for the last four projects
Logistics, cleanliness, order and safety	Random material, waste and people movement with long waiting times	Most materials and waste with JIT movement, roles and discipline developing	Materials, waste and people move JIT with minimum buffers
Risks	Day level scheduling, with +-10% overal accuracy	Minute level scheduling and full transparency, still many missed takts and train seizes	Minute level scheduling and full transparency. No interruptions to production flow
WIP Max	20 man years	200 man hours	200 man hours
Source:	(Douglas 2016)	Own data	Own data

Although the differences seem great, many of these differences have been self-imposed by construction industry. The differences related to scope and duration do not really matter because they impact the scale of planning only. The problem of fragmentation is currently being solved with new contract forms emphasizing collaboration and rewarding innovation. Different risk factors can easily be taken into account with the same approach as described here related to material delivery uncertainties.

COMPARISON OF PROCESSES

The process in this case study and the process described for construction (Frandson, Berghede and Tommelein 2013; Frandson and Tommelein 2014) have several similarities and differences. The overall approach is pretty well aligned and is based on having a standard duration for each trade/wagon in a location but there are many important differences which will be discussed next.

Setting the takt time in this case study is a mathematical exercise depending on the number of cabins, scope (man-minutes / cabin) and project duration (mandated by the Owner). Frandson, Berghede and Tommelein (2013) define two alternatives to define the overall takt time. The first one is based on duration to complete work and the second is to consider available resources, identify the bottleneck, study if the bottleneck's rate can be improved and use the improved rate as the achievable demand rate. The second option is elaborated and seems to be preferred by the authors. For the case company, it is impossible to compromise on customer's lead time due to Owner's high opportunity cost. It forces the team to always find a way to achieve the required lead time.

Locations are very clear in cabin refurbishment projects and their scope is not highly variable. In building construction, the locations are collaboratively defined with the specialty trades based on their preferred work-flows based on batches of work that take the same time for each trade to complete (Frandson, Berghede and Tommelein 2013). The sequence is collaboratively designed with the subcontractors. Subcontractors may have to compromise in order to achieve the project goals. In this cabin refurbishment project case, these compromises are not required because all workers are directly controlled by the contractor.

Balancing the work is based on man-minutes in the cabin refurbishment case study and durations in the Takt time planning approach (Frandson, Berghede and Tommelein 2013). Durations are used in construction probably because of the lack of availability of detailed productivity data. However, man-minutes per cabin make it possible to calculate crew sizes to achieve a given duration which is not possible based on duration. This may result in tighter takt times and improve learning from one project to the next. Both approaches call for a capacity buffer, scheduling less work than required to allow for variation.

Logistics get a lot of attention in this case study but have not been discussed extensively in Takt time planning approach for construction. Logistical constraints are likely to be larger in cabin refurbishment but similar approaches could be implemented in construction.

COMPARISON OF RESULTS

Very few case studies of takt time planning report empirical results. Frandson, Berghede and Tommelein (2013) report that the duration of exteriors decreased from 11 months to five months but they do not report the impact on quality or Work-in-Progress. The results from this case study show that it is possible to achieve huge benefits in terms of quality, productivity, work-in-progress and cycle time. The benefits keep increasing through experience, demonstrated by the improvement between the first takt time planning project to the latest of similar scope.

IMPLICATIONS TO LEAN CONSTRUCTION

This case study illustrates what impacts a thorough lean transformation can have in a production process which is close to construction. Although there are several important differences between ship cabin refurbishment and building construction, the production systems are roughly analogous and it is possible to see the potential benefit of implementing location-based techniques. The external pressure to reduce lead times was a huge factor forcing the case company to overhaul their processes. External pressure of such magnitude is currently missing from construction.

CONCLUSIONS

Takt time planning process has been described in Lean Construction conferences but few empirical data have been reported. This case study shows the huge potential of improvement by implementing location-based techniques in a similar production system. The case company was able to reduce cycle times by 73%, quality defects by 99% and Work-in-Progress by 99%. Although differences in production systems may make the same magnitude of results difficult to achieve in building construction, they show that the improvement goals set in construction have been too low, perhaps due to lack of external pressure. Future research is required to calculate similar metrics in construction projects and compare and contrast the findings with these results.

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TOWARDS A MODEL FOR PLANNING AND CONTROLLING ETO DESIGN PROJECTS

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ABSTRACT

In the modern engineering environment design projects have become increasingly complex; this calls for an updated perspective on how to plan and coordinate design projects. This paper describes the identified premise that will lay the foundation of the development of a model for planning and controlling such projects. The premise includes principles, requirements, and methods derived from theories around subjects, such as, production theory, lean and agile. The distinctiveness of the design process has been central when setting the premise for the model.

KEYWORDS

Design, coordination, control, complexity, ETO, maturity levels, Agile, LPS

INTRODUCTION

Design as a phenomenon is characterized by iterations, puzzle making and problem solving. Moum (2008) applies the metaphor playing jazz and baking bread to illustrate that design is comprised of both reflective (Ellegård et al. 1992) and linear elements. Learning and gradual maturation characterizes, in particular, the “jazz” part of the design process (Kalsaas and Moum 2016). Design can also be understood as a wicked problem. Rittel and Webber (1973) characterize a wicked problem to have no stopping rule, and solutions to wicked problems are not true-or-false, but good or bad. A wicked problem is made up of complex interdependencies. The effort to solve one aspect of a wicked problem may reveal or create other problems. The complex interdependencies can be described as reciprocal (Thompson 1967) between different disciplines in design.

Previous literature has covered several aspects regarding lean design and engineering projects. Kuprenas (1998) provides good insight in how an engineering organization can be reorganized to become lean. Performance measure, which will be an important aspect of a design management model, has been covered in several previous papers, such as in Serpell and Alarcon (1996). There has also been done work on specific challenges such as partnering by Howell et al. (1996), and design and documentation deficiencies by Tilley et al. (1997). Ballard and Koskela (1998) state that “*one major reason for the poor level of design management has been the*

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lack of solid conceptual foundation." They conceptualize design into the conversion, flow, and value generation view. Freire and Alarcón (2002) somewhat criticize this approach, and adds several tools to enable lean design management. In this paper the intent is to take this idea one step forward, and move towards a model for a specific type of design projects, in this case ETO projects. This model can then be tested, and an attempt at creating a generic model can be realized.

The Last Planner System (LPS) (Ballard 2000) was designed to handle both construction and design. However, Ballard did not test the system in the design phase of construction in his doctoral thesis. Several attempts has been made to apply LPS in engineering for some time, but it has proven challenging since the associated tasks, to a substantial extent, are prone to significant changes. Furthermore, it has been demonstrated that the learning aspects and the gradual maturing of design objects are challenging to handle[4]. It seems like there is an emerging realization that LPS needs to be further developed or complemented with other methods to handle such challenges. This paper presents the preliminary development of a new execution model for design and engineering which addresses the aforementioned issues, this is our primary objective. We believe that this can be accomplished by building on some of the principles from LPS (Ballard 2000). Koskela et al. (1997) conclude that LPS can be used in design management, which further strengthen that this is achievable.

The topic of our research is related to the development of a construct for execution and control of design projects, grounded in the dynamics of design. For this purpose we apply constructive research (Lukka 2003). The relevance is tied to the benefits of being able to manage design project in a predictable manner, while providing customer value such as build-ability and laying the foundations for proper operations (end use).

We apply a case from the oil and gas sector for our initial development of the model. The case company designs and builds mechanical constructions for offshore drilling. The constructions are the foundation for machines and equipment used when drilling for oil and gas. The case company usually acts as a supplier to companies that deliver turn-key drilling modules to the oil companies. The equipment supplier provides our case company with system engineering. The engineering phases in the case company are defined as: layout, design, detail design and drawing. We limit the case to study engineering-to-order (ETO) projects, which means the case company is also responsible for fabrication. Engineering-Procurement-Construction (EPC) contracts are utilized.

The following section highlights the principles and requirements of the construct. Thereafter we address methods and techniques we want to extract ideas and elements from. Finally we address verification issues to somewhat validate the construct before we conclude and address some further development issues.

PRINCIPLES AND REQUIREMENTS

Principles lay the foundation for the Design Execution model (DE-model), and steer the direction in which methods and techniques should be included. The model should be based on the dynamic of the design processes, thus it needs to take some of the characteristics of design into account. The phenomenon of design is characterized by

[4]Based on unsystematic empirical data/experience

a balance of creativity and rationality (Bonnier et al. 2015). The process of envisioning and developing can be described as creative, iterative and open-ended. Engineering design involves a systematic and intelligent generation of design concepts in conformance to specifications needed to realize these concepts (Dym et al. 2005). Ballard (1999) argues that design requirements and their respective solutions evolve as the process progresses, which is what Thompson (1967) depicts as reciprocal dependencies: relationships where output from one activity establish the next. According to Kalsaas and Sacks (2011) a better understanding of the different types of dependencies among management will result in improved decision making in regards to how work is organized, this could be accomplished either by avoiding the most complex dependencies or by meeting them with awareness. This relationship among activities needs to be taken into account in the DE-model. Thus, it is required that the model focus on the interfaces which exists among these activities, in order to handle the reciprocal interdependencies.

Another important aspect of design is the learning and maturing process that occurs throughout the process. Kalsaas (2011) conceives design as a learning process where one develops and optimizes a solution. Consequently, the DE- model must take the aspect of learning into account. This can e.g. be done by addressing learning and maturing in selective milestones in the project. For example, a retrospective meeting,which will be in line with the last principle of the Agile Manifesto (Beck et al. 2001), after each milestone where the team reflects and adjusts its behaviour, could enhance the learning process.

The design process can be considered as a process which produces information, as stated by Bauch (2004)*"Product development [...] can be understood as some kind of information creation factory."* Thus, the principles of production should be highly relevant in the context of developing an effective DE-model.Koskela (1999) proposes five principles for a production control system: (1) Assignments should be sound regarding their prerequisites, (2) the realization of assignments is measured and monitored, (3) causes for non-realization are investigated, (4) maintaining a buffer of tasks, (5) in lookahead planning, prerequisites of upcoming assignments are actively made ready. Maybe except for the buffer-aspect, there is little reason to believe that these principles do not hold true in the context of design, and the DE-model should take the principles into account.

The design process plays a crucial role throughout the product life-cycle, and affects both the manufacturing and operational phases. It is essential that the product design is precise at the earliest stages of development. The design phase typically accounts for approximately 5% of a products total cost, but it affirms to 75% of a product's total manufacturing cost, which indicates the importance of good design (Verma and Dhayagude 2009). Failure to involve manufacturing early has the capacity to create waste, and will likely affect these affirming costs greatly (Bonnier and Ose 2015). Consequently, the principles of the DE-model should address this issue. In the context of concurrent engineering, Smith (1997) summarize the fundamentals as: *"the increased role of manufacturing process design in product design decisions, the formation of cross-functional teams to accomplish the development process, a focus on the customer during the development process, and the use of lead time as a source of competitive advantage."* Obviously, all products have constraints imposed by the manufacturing process, which will affect the details of the product design. If such constraints are addressed early in the process, an opportunity to reduce manufacturing costs and improve product quality emerges (Smith 1997). Thus, in accordance with the fundamentals of concurrent engineering, one of the principles of the DE-model should be to involve manufacturing and the customer early in the design process.

Ballard (2000) introduced the terms negative and positive iterations, where positive iterations are the processes that create value. Negative iterations are connected to what is perceived as rework in the design process, and what iterations that can be removed without decreasing the level of value creation. However, it can be a challenging effort to separate these since the path to the desired result is commonly unknown. This implies that the DE-model should encourage positive iterations. If the various disciplines move forward in an agreed phase, the amount of negative iterations and waste should diminish. This can be seen in relation to takt time planning. Takt time is explained by Frandson et al. (2015) 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)."* This should also hold true for the production of information in design. Thus, a principle of the DE-model should be to enable takt, in an attempt to reduce waste and negative iterations.If it is not possible to enable takt, the various disciplines should at least move forward in an agreed phase speed.

Toyota has grown to become the global market leader in the automotive industry, perhaps only challenged by Volkswagen (Deutsche Welle 2015). The growth and market share of Toyota certainly sparks the interest to study the company's practices, in an attempt to identify its reasons for success. Singer et al. (2009) write that *"Many believe that Toyota's design process is one of the major accomplishments that have enabled them to be so successful."* The paradox in their design process, compared to other car manufacturers, is that Toyota severely delays critical design decisions, while still having a time to market that is shorter than their competition. Singer et al. (2009) explain that the reason for delaying decisions is connected to costs, knowledge, and influence.While Toyota has shared several details of their manufacturing practices, they have perhaps not been quite so loquacious and eloquent about their design process. Some clues to Toyotas design process can be found in the works of Morgan and Liker (2006). They identify 13 Lean Product Development (LPD) system model principles, which make up the Toyota DNA. Toyota DNA is what Toyota calls its process and culture, in an attempt to explain the difference between their company and others (Singer et al. 2009). Inspired by these principles, some principles of the DE-model can be suggested: establish a working definition of value in order to reduce waste, standardize where possible in order to reduce variation, and using visual management.

Set-based concurrent engineering (SBCE) can be identified as one of the reasons for Toyota's successful design process. The typical process of SBCE starts with developing sets of design for a given design problem. Instead of striving to identify one solution, several design options are developed, and gradually eliminated, until only one remains. A complex design problem requires the involvement of several engineers or functional groups. Thus, SBCE advocate that sets of solutions to the problem should be developed by these groups from their perspective. Later, these groups interact with each other by comparing the sets. They look for the regions that overlap in their design alternatives; furthermore these regions are narrowed in parallel to the point where one solution is left. One benefit of this approach is that the knowledge possessed by highly specialized engineering functions, that is typically difficult to share, is re-combined from the independent solutions into the integrated final solution (Bernstein 1998). The benefits of this approach to design are that SBCE provides a mechanism that enables managers and engineers to delay decisions. Even while they still are developing a product. Bernstein (1998) summarizes the benefits of SBCE as*: "The effects of SBCE, therefore, are to delay the commitment of costs and to increase management influence late in the development process."* However, implementing a SBCE-environment might be too radical a change for most companies. Still, the benefits of SBCE can be somewhat preserved as a principle of the DE-model: delaying commitments of costs when the commitment is not required as a prerequisite for downstream processes. In other words, the principle can be that engineering information is pulled from downstream processes when possible.

SCRUM

Agile Methods are a response to the need to handle the rapid changing requirements in the software development industry (Cohen et al. 2004). Although these methods and practices vary, they share some common principles and practices, such as incremental, iterative development cycles in order to complete projects (Abbas et al. 2008).

The term Scrum has its origins from rugby: going the distance as a unit passing the ball back and forth. The analogy depicts the continuous interaction of a cross-functional team whose members work together from start to finish, towards a common goal (Takeuchi and Nonaka 1986). The methodology shares some of the main practices of the other Agile Methods, such as incremental and iterative development cycles. The customer requirements act as a driver for the iterations. The cyclic development process continues until the project is no longer funded (Schwaber 2004). At the beginning of each iteration the development team reviews what has to be done. These iterations are termed as Sprints, and typically last for 2-4 weeks (Hoda et al. 2008). The team determines what needs to be done and selects the most appropriate way to implement functionality. This creative process is the core of the Scrum's productivity. The roles that are typically involved in this process are Scrum Master, Product Owner, and of course the development team. All managerial responsibilities are divided among these roles (Schwaber 2004). The Product Owner represents the customer's interest and is responsible for preserving the right business perspective (Hoda et al. 2008). The Product Backlog is the list of requirements which the Product Owner uses to ensure that the most valuable functionality is developed first and then built upon. The elements in the Product Backlog are prioritized in order to aid the development team when deciding which functionality to work on in the upcoming Sprint. The development team is a self-organized unit, and is comprised of personnel which are cross-functional. Typically the development team consists of 5-9 members. The team is responsible for incrementally transforming the Product Backlog items into functionality through each Sprint (Schwaber 2004). The Scrum Master is a member of the development team and acts as a facilitator for the Scrum process and is responsible for removing any impediments that might obstruct the development team in their daily chores. In addition, the Scrum Master is also accountable for teaching Scrum to everyone involved in the project (Sutherland and Schwaber 2011). These three aforementioned roles are the ones that have committed to the project and are the ones responsible and with authority. Others might indeed have an interest in the project, but they are not authorized to interfere with the development process (Schwaber 2004).

The Sprint Planning meeting initiates each Sprint. This is when the Product Owner and the development team collaborate about determining what functionality to develop and implement during the upcoming Sprint. Typically, the top prioritized items from the Product Backlog are chosen (Schwaber 2004). The selected items combined are the elements which comprises the Sprint Backlog, which refers to the tasks needed in order to implement functionality in the impending Sprint (Hoda et al. 2008). Every morning the team gets together for a 15-minutes meeting called the Daily Scrum. The objective of the Daily Scrum is to synchronize the work of all team members daily and to schedule any meetings needed to ensure progress. A Sprint Review meeting is held when a Sprint comes to an end. The development team presents what has been achieved during the Sprint to the Product Owner for review. Subsequently a Sprint Retrospective meeting is held, which purpose is to make the development process more effective and enjoyable for the following Sprint (Schwaber 2004). Furthermore, the Sprint Retrospective provides the team an opportunity to learn from the past and adjust its course accordingly (Landaeta et al. 2011). Adaptation and learning are crucial aspects of delivering value to the customer according to the agile philosophy(Highsmith 2009). Together, the four aforementioned events establish the empirical assessment and adaptation practices of Scrum (Schwaber 2004).

Scrum appears to be based on the same paradigm as LPS when it comes to collaboration and is based on a relational approach, not transactional. We have made the proposition that elements from Scrum has the potential to enhance LPS's applicability to engineering. In particular the challenges associated with handling significant changes could be mitigated by applying Sprints. Events such as Sprint Planning and Sprint Review meetings might ensure close and continuous collaboration between the team and the customer, and could act as a forum to handle substantial changes. Minor issues may well be handled by the autonomous teams in the Daily Scrum meetings. The challenges related to learning could be handled by applying Sprint Retrospectives to supplement the Sprint Reviews. This would ensure that both the product and the work process itself are continually evaluated. We find these ideas of incremental problem solution and iteration to be promising for handling and controlling the wicked challenge inherited in design.

THE EXECUTION DESIGN MODEL

The conceived model is constructed based on ETO-projects and EPC-contracts. The point of departure is from the point in time where the contract is signed. By that time the project team got an idea of the construction method and which work the company will outsource, which follows from the tender process. From the tender process the team is moreover to some extent aware of risks, complexity and hours needed in the project. The model is constructed in five steps:

1. Master plan Engineering (milestone plan)
2. Phase plan (reversed scheduling based on functional milestones)

3. Flexible takt plan made up of design work packages and Sprints (functional engineering packages managed by self-organized teams)
4. Manual work scheduling internal to each Sprint
5. Sprint reviews (root causes to deviation, learning – continuous improvement)

The model is based on that a design project is divided into sections / control areas. The division is often related to the needs of fabrication. The milestone plan is the key element for keeping the project on time. If necessary, extra resources are used to successfully achieve each milestone. The milestones used are often generic within a business, based on the methods and logic that repeats itself, even though projects have many unique properties. However, lead times and time determination of milestones differs from time to time, such as different sectioning.

The stage plan prepares a sequence of activities that must be performed to reach each milestone for each section / control area. Some milestones are global, while others are connected to the section / control area. Iterations, incremental design, and gradual maturing, are handled in work packages and Sprints. Each work package consists of one or more Sprints. Each Sprint is handled by autonomous multidisciplinary groups.

In the takt plan Sprints, order, and the amount of time teams have at their disposal, are identified. The takt plan is balanced against the resource capacity. The autonomous groups create their own flexible work schedules. A relevant critical question is if the takt principle is too rigid for design work. This is easily imaginable at first glance, but for any method we need a predictable progress, which also holds true for design. The idea is to build flexibility into the Sprints for the iterations and the interactions where this is considered necessary. Here the self-organized teams play a key role, and they must deliver, but they decide how they solve the tasks at hand, and retain responsibility for the detailed planning.

Sprint reviews are an important meeting, in order to control quality against criteria and to apply systematic learning, where experiences and causes of any challenges are shared throughout the project.

CONCLUSION

Within all organizations, a standardized method of executing complex projects is essential for a valuable outcome from projects. Such a model is defined as a stepwise definition of what do by whom to execute design projects, based on an execution philosophy. The aim is to speed up design work and to increase the reliability and quality, which require a model that is responsive to the frequent changes, creativity, iterations, gradual maturity, learning and the wicked character of design projects. The benefits are expected to be reduction in cost and waste and increased reliability in term of progress. The relevance is moreover related the great importance of design for value regarding build-ability and the operation phase for end-users.

The model presented in this paper is developed in an attempt to tackle the requirements by implementing different theories and planning methods. While the presented model might require further development, it is in its current state close to ready to be implemented. Thus, the constructed model will be verified and tested in real design projects at the case company.

FUTURE RESEARCH

A more elaborate version of the model will be tested in an ETO project context to verify its applicability. We aim to develop and apply the model, or at least elements from it, on an upcoming project at the case company. It might also be beneficial to look further into the Nexus framework with regards to coordinating multiple Scrum teams.

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APPLYING LEAN TECHNIQUES TO IMPROVE PERFORMANCE IN THE FINISHING PHASE OF A RESIDENTIAL BUILDING

Danny Murguía[1], Xavier Brioso[2], and Angela Pimentel[3]

ABSTRACT

In Peru, the Last Planner System (LPS) is widely implemented by contractors during structural work. However, during the finishing phase, its efficacy is reduced, as teams deal with high levels of variability, uncertainty within supply chains, and unpredictable production capacities among subcontractors. The work structuring is frequently based on a one-week takt on successive floors, and pull planning during the structural work becomes push planning during the finishing phase, as teams impel subcontractors to meet deadlines. All this implies that improved work structuring is needed to enhance the flow of operations during the finishing phase.

To meet this need, we designed a case study in two stages. First, we used direct field observation of a Peruvian building project to describe the current state of the work structuring in the finishing phase. Value Stream Mapping (VSM) was used to identify the productive stream, focusing on the identification of wastes. Second, we applied some Lean techniques during the finishing phase in a large community-housing complex. Our conclusion is that assigning the tasks in sufficient detail and modeling the production units according to the project’s complexity can improve the flow of the finishing stage. The use of flowlines is also recommended.

KEYWORDS

Last Planner System, Pull Planning, Work Structuring, Value Stream Mapping, Flowline.

INTRODUCTION

The Last Planner System (LPS) has been applied successfully during the construction phase of numerous building projects (Ballard and Howell 1994). In Peru, too, LPS has been implemented by major contractors, with several positive results: higher profits (Ballard and Howell, 2004) and on-time completion of design milestones (Arbulu and Soto 2006). Some Peruvian construction companies also implement LPS during the structural phase (Calampa 2014), while in the Lean community, the system has also

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been applied during the finishing phases of building construction (e.g. Brodetskaia et al. 2011; Brodetskaia et al. 2013; Priven and Sacks 2015; Priven and Sacks 2016).

In Peru, it is a major challenge to sustain LPS implementation during the interior construction phase. Production teams deal with high levels of variability, and cultural issues regarding subcontractor commitments in the construction process make it difficult to sustain LPS from start to finish. Weekly meetings only have to do with construction assignments, omitting analysis of constraints and the make-ready process (Brodetskaia et al. 2013).

This paper hypothesizes that if a construction project were to apply Lean techniques under LPS during the finishing phase of residential buildings, the overall performance of the system would improve. A case study helps to illustrate current practice. First, we use direct field observation and document analysis to determine the way LPS is currently implemented in the finishing phase of a residential building. We employ Value Stream Mapping (VSM) to identify wastes and the productive stream, and to propose a smoother workflow. Afterwards, we recommend new work structuring for the finishing phase, with the use of flowlines to help last planners visualize activities and organize pull planning sessions. A second case study allows us to determine the feasibility of these recommendations and measure percentage of plan complete (PPC) as a performance indicator.

We emphasize, however, that our conclusions are tentative, requiring further confirmation before being applied to the Peruvian housing industry. The results also might be complicated by regional variations in planners' and engineers' behavior.

BACKGROUND

WORK STRUCTURING

Work structuring is the breakdown of both product and process into chunks, separate sequences, and assignments in order to allow the workflow to run more smoothly and with less variability. This in turn reduces wastes and increases value (Ballard 2000). The goal of work structuring is to make the workflow more reliable while delivering value to the customer. In particular, work structuring views a project as consisting of production units (PUs) and work chunks (Ballard 2000).

VALUE STREAM MAPPING (VSM)

According to Rother and Shook (2003), a value stream consists of all the actions (both value-added and non-value-added) required to bring a product through the production flow from the raw material to the hands of the customer. As such, Arbulu et al. (2003) have introduced VSM as the basis for analyzing the current-state map of construction supply chains. VSM is considered one of the gateways for Lean production precisely because it permits a systemic view of the value flow in the production process, identification of real problems and wastes, and recommendations for improvement (Pasqualini and Zawislak 2005).

LOCATION-BASED SCHEDULING

Location-based scheduling methods explicitly consider location as a dimension in the production process. A project can be modeled as a series of locations in which activities flow through different units in turn. Thus, in each location, activities are linked through a logical relationship network. This allows for easier planning of continuous resource use, which in turn enables cost savings and fewer scheduling risks, since subcontractor crews can be kept on site (Soini et al. 2004). Line of Balance (LoB) is one such method, dividing a project into repetitive and equal units. Similarly, the flowline method is focused on a series of locations, which may vary in size or in the tasks to be performed there (Kenley and Seppänen 2010).

LITERATURE REVIEW

Interior finishing work is typically characterized by uncertainty, instability, and waste. There are no technical constraints requiring that such work be performed floor by floor, and usually multiple subcontractors carry it out. Quantities often vary between locations, and jobs usually have long lead times. Also, subcontractor production capacity is unpredictable, causing turbulent workflow (Brodetskaia et al. 2011). Re-entrant flow patterns, in which crews return to a location multiple times, make it more difficult to plan and control tasks (Brodetskaia et al. 2013).

In order to understand dynamic flow during the finishing phase, Brodetskaia et al. (2011) devised a workflow model for systems and interior finishing work, taking into account features such as non-linear tasks, instability, and re-entrant flow. The model enabled evaluation of the impact of management policies on production flow, in different levels of detail. More recent research yields new insights into how LPS works. Even when implemented partially, LPS still improves workflow, as it engenders a social network among subcontractor trade crews (Priven and Sacks 2015). As such, LPS has a social impact, building relationships across projects, and can contribute to improved coordination. To strengthen these social networks, Priven and Sacks (2016) devised an artefact called Social Subcontract (SSub), which aims to improve communication, mutual respect, and collaborative behaviour among subcontractor trade crews. Studies have concluded that SSub together with LPS at once leverages the make-ready process, improves coordination, and facilitates workflow more than LPS alone.

The question driving our research is how to strengthen the implementation of LPS in the finishing phase of building construction in Peru, where small subcontractors abound. Using the perspectives previously discussed, we seek to develop basic workflow and scheduling models by means of case studies.

CASE STUDY 1

PROJECT BACKGROUND

The first case study focuses on the finishing phase during the construction of a residential building. Said building consists of seven stories covering 5,800 square meters, and its 30 apartments display high-quality finishing in an exclusive area in Lima. The project was studied over two months to better grasp the subtasks and their interactions, identify wastes, understand current work structuring, and interact with last planners and production engineers. The tasks monitored were (1) painting, (2) tiling, (3) door installation, (4) closet installation, and (5) kitchen-cabinet installation. Each main task in this phase has a special subcontractor.

WORK STRUCTURING

The production unit of many tasks is one full story per week. The chunks of work are oversized, and little control can be exercised in such circumstances. Likewise, tasks are not planned at the operational level. There are sub-tasks that divide work into other activities, which are not considered. The assignment of resources is only based on subcontractor's experience. This myopia makes it difficult to identify constraints on time.

VALUE STREAM MAPPING

Based on the observations, it was possible to produce a VSM for each task analyzed. For example, Figure 1 shows the painting task for a production unit of one full apartment. It is noteworthy that the added-value activities constitute 40% of the lead time of the activity. Sub-processes in general tend to be planned; however, in this case, only three out of ten were laid out beforehand. There is a huge gap of 40 days during which any sub-process is performed in the production unit. If we analyze the Value Stream Map below, we see there is much room for improvement.

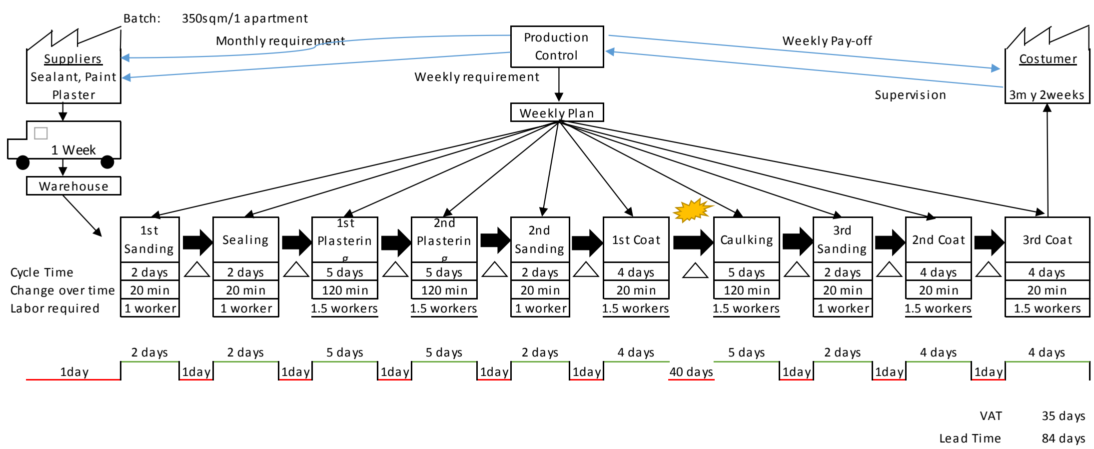

Figure 1: Value Stream Map of Painting

WASTES

In compliance with the transformation-flow-value theory of production, Bølviken et al. (2014) developed a taxonomy to categorize the different wastes that occur during construction. Three main categories of waste were established: material wastes, time loss, and value loss (Bølviken et al. 2014). Applying this taxonomy, the principal wastes during the finishing phase of this building project are: (1) Material loss: Plastic and cardboard are used to protect finishing at all times, due to continuous presence of crews for re-entrant flow (Brodetskaia et al. 2013). Also, the level of prefabrication is too low, since a large amount of raw material reaches the construction site; (2) Time loss: The amount of time between sub-processes is too high. Some 40% of painting lead time or 5% of kitchen-cabinet-installation lead time involves value-added activities. The rest of the time, there are no crews working. There are many unprocessed materials, and a high rate of inventory loss; (3) Value loss: Some tasks have a high incidence of non-conformities due to the artisanal processes, low tolerance, and strict quality control. Moreover, if a design does not meet customer requirements once installed, it is changed. Safety and health issues also affect workers.

CONTRACT RELATIONS

The contract with the subcontractor is only based on take-off, unit price, and the start and end dates of tasks contracted. However, most contractors focus principally on the unit price. Very few elements are controlled, collaboration and pull planning are confined to the first weeks of tasks, and reassignment of crews is generally left to the subcontractor. The contractor only pushes the subcontractor to meet the completion deadline.

LPS IMPLEMENTATION SHORTFALLS

Some conclusions can be drawn from this first case study: (1) The phase schedule only considers main tasks. The production unit is either one full story (e.g. painting) or one full apartment (e.g. tiling, doors); (2) At the beginning of the phase, pull planning is used with very few subcontractors; (3) During the look-ahead planning, phase-schedule tasks are not properly broken down into operations. This is because there is little knowledge of subtasks; (4) Weekly meetings only serve to track achieved progress and plan again, based only on the foreman's word, with little analysis of constraints; (5) Make-ready activities are not indicated transparently. Weekly work plans often have to be restructured; thus the flow becomes difficult to manage; (6) In the end, pull planning is neglected, and planners push subcontractors to finish their tasks by the contract's completion date; and (7) There are many invisible losses. On average, during 90% of the lead time of major activities, no subtask is performed. This results in extended schedules.

LEAN TECHNIQUES FOR IMPROVEMENT

PRODUCTION UNITS

In the first case study, work structuring in the finishing phase focuses on one full story. For example, the tiling crew must finish their activities (nine bathrooms and four kitchens in Figure 3) for one floor in a single week, and then move on to the next story. It is necessary to reduce the batch and to plan activities with no interference, considering the position of five production units. These production units are (1) bathrooms, (2) kitchens, (3) closets, (4) doors, and (5) painting. The first three PUs are in different locations in each story, so crews could be allocated at the same time without interfering with each other. By contrast, the last two PUs should be scheduled independently, because they require most of the space within the story.

The next step is to identify the correct subtasks for the project and visualize these activities at the right level (Dave et al. 2015). In the first case study, the subtasks and work sequence were identified as shown in Table 1. For example, the floor tiling crew moves from bathroom 1 to bathroom 9 and hands over the work to the wall tiling crew. In turn, the wall tiling crew yields to the grouting crew, and so on.

Table 1: Subtasks within production units

Subtask	PU1 Bathrooms	PU2 Kitchens	PU3 Closets	PU2 Doors	PU2 Painting
A	Floor tiling	Wall cabinet	Structure	Frames	Sealing
B	Wall tiling	Base cabinet	Doors	Doors	1^{st} Screeding
C	Grouting	Granite board	Shelves	Frame painting	Sanding
D	Marble board	Wall Tiling	Drawers	Door painting	1^{st} Coat
E	Sanitary	Sink	Knobs	Knobs	Screeding&Sanding
F	Cabinet	Faucet	Sealing	Doorpost	2^{nd} Coat

FLOWLINE

According to Dave et al. (2015), the steps necessary to implement an integrated planning and scheduling system are: (1) create the location breakdown structure, (2) identify activities at the proper level of detail and how they relate to one another, (3) apportion activities based on take-off, consumption, resources and the know-how of the specific trade contractor. On the basis of steps 1 and 2, Figure 2 shows the flowline of the aforementioned painting production unit 5. This level of detail would help last planners visualize the work, detect process clashes, identify constraints, and have better-informed pull planning sessions.

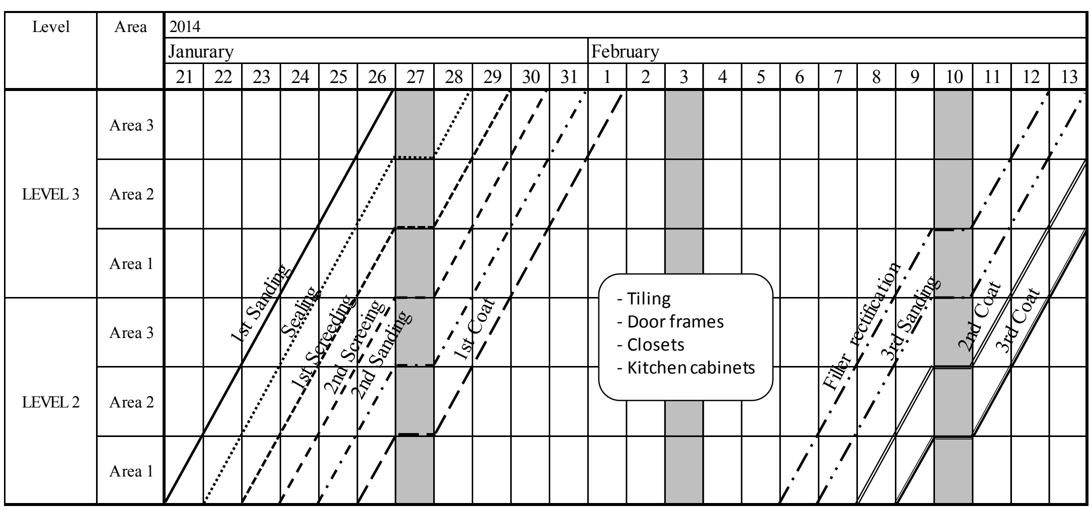

Figure 2: Painting flowlines

CASE STUDY 2

PROJECT BACKGROUND AND CONTRACT RELATIONS

The second case study focuses on a large community-housing project. The project consists of 28 five-story buildings occupying 99,330 square meters. Each building includes 100 flats with basic finishing and highly repetitive processes. The phase studied lasted three months, and the tasks monitored were (1) painting, (2) doors, (3) windows, (4) tiling, and (5) flooring.

The contractor had previous experience in community housing. In the finishing phase of the previous project, the team faced some constraints in terms of the design and the development of the work structuring. One of the problems was the contracts, as the documents only specified the start and end dates, tolerances, and cost. The flow process was not part of the formal agreement with the subcontractors. Therefore, they were reluctant to attend meetings to track their progress, engage in collaborative planning, and analyze underperformance. Based on this experience, the second case study requires the subcontractors to attend the weekly meetings.

WORK STRUCTURING

The production units were designed on the understanding that community housing has less finishing work than other residential buildings. For instance, the project does not include kitchen cabinets, closets, or wall tiling. Because of this, the work chunks were divided into two production units: (1) Bathrooms, kitchen, and laundry room; (2) Living room, dining room, and bedrooms. Assigning different crews for each production unit allows for reduction of conflicts in the field, and each subcontractor can estimate his workload independently.

Bedroom with floor, window, door and painting

Kitchen with basic finishing: floor, cabinet, and sink

Figure 3: General plan divided into two production units

PULL PLANNING SESSIONS

Contracts with subcontractors were key drivers for participation and attendance in pull-planning sessions. In these collaborative meetings, planners and subcontractors discussed the possibility of work completion in the field, taking into account the pull plan, the daily workload, the available resources, and the time of day that activities were to be completed.

To generate a flowline, it is possible to define each location and timeframe in self-contained boxes. In other words, all work related to that activity and location should be completed within the time-location box (Dave et al. 2015). The use of these boxes is useful for visualization purposes in highly repetitive projects with short schedules. For example, Figure 4 shows the flowlines for the first production unit.

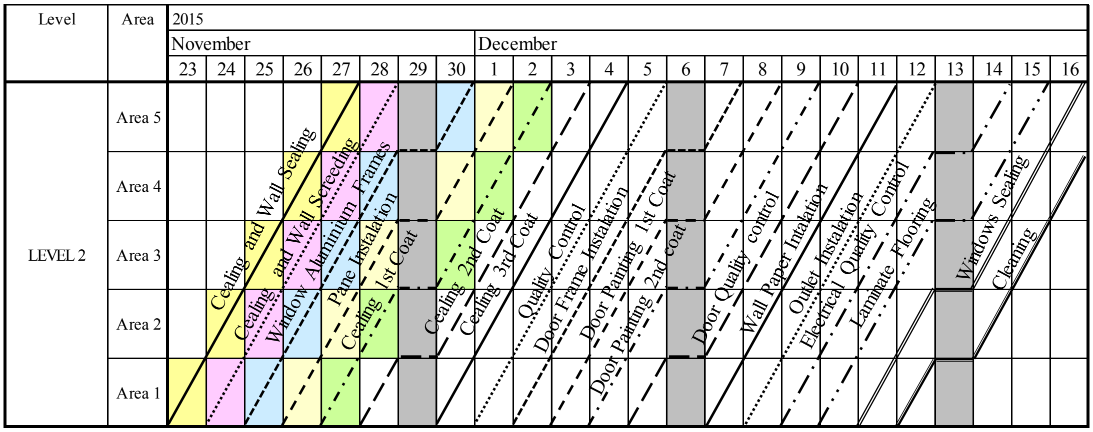

Figure 4: Flowlines with boxes in the second production unit (Adapted from Dave et al. 2015)

Additionally, local trade contractors agree that repairs due to non-conformities hinder their workflow. Going back to do these repairs is time-consuming and causes production delays. To protect the weekly work planning, the contractor included an additional crew to repair non-conformities, so as to guarantee flow within the subcontractor's crew. The subcontractor assumed the cost of this crew, subtracting it from their monthly payments. In this way, the boxes are finished on time, and clashes are avoided.

Even though the contractor understood the use of the flowlines and their application, in practice, for simplicity, and in the context of highly repetitive activities, tasks were controlled through Excel schedules. The contractor made the flowlines for purposes of visualization. Hopefully, planning and control with flowlines will be used in the future with more complex projects.

PPC AND WEEKLY WORK PLANNING COMPLIANCE

During the early weeks of the phase, PPC was 60%. It was at this point that the contractor and the subcontractors agreed on the inclusion of the additional crew that would deal with non-conformities and facilitate the flow of the subcontractor's crews. As a result, PPC increased to 75%. The phase was later delayed two weeks, but this was the result of the client's having purchased products that arrived late on site.

CONCLUSION

The case study suggests that LPS implementation during the finishing phase in residential buildings improves the performance of the production system. It is necessary to redesign the production units, grouping activities according to location and similarity of tasks rather than in terms of a full apartment or story. In addition, each production unit must be defined with work chunks at the right level. Otherwise, it will be difficult to observe the workflow during the planning process, and conflicts will arise in the field. The pull planning process also requires better visualization: here flowlines can be used to good effect, and hopefully the method will be used in the company's future projects. Full deployment of these strategies, however, requires training and leadership among the managers of both contractors and subcontractors. An additional crew to repair damages or finish incomplete work was a local strategy tacitly agreed upon with subcontractors. Contracting relationships are vital to sustain LPS implementation within the world of small subcontractors. The general contractor needs drivers to steer production control. Attendance at weekly meetings and resource allocation have a direct effect on improved workflow and cooperative behavior (Sacks and Harel 2006).

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A FRAMEWORK FOR INTEGRATING TAKT PLANNING, LAST PLANNER SYSTEM AND LABOR TRACKING

Samir Emdanat[1], Meeli Linnik[2] and Digby Christian[3]

ABSTRACT

This paper proposes a framework for incorporating direct field labor hours and costs into an overall production strategy centered on Takt Time Planning (TTP) and the Last Planner® System (LPS). An integrated tracking tool, vPlanner Production Tracker, has been developed to associate labor information with production activities utilizing the same database. The association of field labor hours including budgeted, estimated, and actual with production activities provides an early indicator of risk on projects. The proposed framework improves the consistency and efficiency by which the information is created and maintained so that the system can be scaled to support large projects that span multiple years. This is done to shorten the cycle time between monthly financial forecasting and field labor utilization. The goal is to improve the effectiveness of identifying and mitigating risks of field labor overruns and also the realization of savings opportunities due to improved field labor utilization. The paper outlines the improved workflow processes and presents an analysis of the data collected over several months from a pilot project.

KEYWORDS

Takt Time Planning, Last Planner System, Production Planning, Labor Tracking, PDCA

INTRODUCTION

LPS is a production management system designed to improve workflow reliability by shielding near-term work from the variability and the uncertainty surrounding downstream processes (Ballard and Howell, 1994). Detailed handoff work plans for near-term work are created through collaborative planning among those team members responsible for directing the performance of the work. One of the fundamental elements of LPS is the systematic application of the Make Ready Process (MRP). This process ensures that all known constraints that may affect planned activities are identified, planned, and resolved before the start dates of the impacted activities (Ballard and Howell, 1997). The systematic application of the system in its entirety creates a steady stream of unconstrained work that can be performed with more certainty in alignment with overall project target milestones.

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TTP aims to reduce the variability in the downstream processes themselves by pacing the production rate of standard activities across right-sized geographic areas within distinct work phases (Linnik et al. 2013). This is achieved by fixing the durations and varying the crew sizing of standard activities performed by the various trades in succession. The end objective is a steady stream of predictable work, performed in the proper sequence, across the defined geographic areas, and, with appropriately planned crew sizes. This disciplined planning approach aligns not only the workflow at the site, but also the overall flow of materials and information through the supply chain starting in design and moving into detailing, fabrication and delivery processes required to support the Takt sequence. Recent experimental studies (Frandson et al. 2014) suggest that TTP has the potential of improving LPS implementations because of its focus on the design of predictable flow of materials and resources across clear geographic locations.

The effects of implementing TTP and LPS on improving field labor forecasting have not been explored. Currently, a long feedback loop exists between monthly financial forecasting and production labor utilization. This results in poor reaction time when attempting to adjust the production system to mitigate financial risk or recognize savings opportunities due to labor utilization. The authors have been collaborating on a new approach to reduce the duration of the feedback loop. This paper presents the results of this collaboration and introduces a framework for incorporating direct labor hours and costs into an overall production design strategy centered on TTP and the LPS. It presents this in the context of ongoing work on a large hospital project in San Francisco, California, namely the St. Luke’s Campus Hospital (STL) presented later in this paper.

An integrated tracking tool, namely vPlanner® Production Tracker, has been developed to associate labor information with production activities within the same underlying database. It integrates labor information with the existing features of the base vPlanner system database. The software has been used by the STL project team since 2014 to manage TTP information on a rolling basis spanning at least six months of future activities. In addition, the team uses the system for managing LPS processes including the Make Ready Planning, Weekly Work Planning, and Daily Commitment Management.

The use of vPlanner on the project was required by the owner. Sutter Health needed a solution for production management that could accurately represent the highly complex and dynamic networks of commitments that are required to plan the design and construction of its healthcare facilities. Additionally, Sutter needed a solution that allowed rapid revisions of that complex network as challenges were uncovered during Make Ready Planning. For those reasons, among others, Sutter Health selected vPlanner as its tool of choice for planning work on its most complex and challenging projects including the STL project.

The development of the Production Tracker tool is an attempt to resolve some of the workflow challenges that teams face when implementing TTP and LPS using separate processes and tools that are manually coordinated with the associated familiar problems of human error, duplication and lack of visibility of the two-way impacts of each system on the other.

This paper presents the objectives for developing and implementing this framework and the associated tool, the problem it solves, the initial findings, and outlines directions for future research to extend this approach.

OBJECTIVES

The association of field labor hours (including budgeted, estimated, and actual) with production activities improves the alignment between resource assumptions and work execution. This provides an early indicator of risk on projects that is mainly associated with overruns on field labor hours. Additionally, it provides an opportunity to involve those directly responsible for managing the work to validate and inform budgetary and labor assumptions before the work is executed. The resulting collaborative nature of the approach promotes transparency, trust, and cross team learning. Below are the main objectives for developing the framework and associated workflows and software solution:

- Reduce the cycle time for data collection and analysis so that teams can react more quickly and mitigate the risk of unforeseen variation.
- Improve collaborative planning aimed at clarity of handoffs and predictable flow by validating resource assumptions prior to work execution.
- Align TTP with resource planning and budget control.
- Reliably execute against those plans using LPS methodologies.
- Ensure uniformity and increase the consistency of data collection and tracking.
- Improve on the overall efficiency by which the information is created, maintained and tracked so that the approach can be scaled to support large projects that span multiple years.

It is important to note that while this approach has merits under a variety of contractual arrangements, it adds the most value in collaborative open-book contracting arrangements such as Integrated Project Delivery (IPD) where the interests of the team are aligned around the success of the project as a whole.

PROJECT CONTEXT

This approach is being implemented on the STL Project; a new 237,000 sq.ft., seven story hospital in San Francisco, California for Sutter Health. The $330 million project is being designed and delivered utilizing an IPD contract. It is due to open in 2019. The open book nature of the project, its size, and the team's commitment to continually improve how they manage work provided an ideal setting for implementing this approach.

The STL team has been using LPS and TTP since the project started and has mastered both techniques. Taking those efforts to the next level was a natural next step for this high performing team. The authors are active participants in this project at different capacities. One is the owner's representative, one is responsible for production management and one is the project's Lean/IPD coach and the developer responsible for the tool used to implement this framework.

The approach was introduced into the production environment in February 2015 which marked the start of construction. Multiple work phases are complete including foundations through concrete deck construction. At the time of writing this paper, the project team has completed over 10,000 commitments and tracked labor data for over

5700 production activities. The completed activities represent approximately 24% of the risk-reward scope of work on the project. The ratio of actual hours against budgeted hours is showing a 7.5% in field labor savings.

The team is currently tracking production activities and field labor hours related to interior construction including fireproofing, MEP systems and framing with the intent to follow this process to project completion. While some risk-reward trade partners are providing labor mix rates and actual costs, the main focus of the pilot implementation was the tracking of field labor hours.

WORKFLOW AND DATA ORGANIZATION

Production Tracker was designed to support the workflows for associating labor hours with Takt activities developed in collaboration with the project team to define the overall process and the desired outcomes. Key team members collaborated over the course of several months to identify the objectives and map out the current and future state workflows for documenting and reporting on this information. The outcome of those discussions informed the design of the Production Tracker software module. The team included the owner, the general contractor's production managers and general superintendents, the financial reporting team, the project managers of the various trade partners and their superintendents. The assembly of this cross functional team was essential to cover all aspects of information flow from daily commitments to financial reporting. This section presents the definitions used to document the various activity types, standard work assumptions, and labor categories. The next section outlines the main elements of the standard future state processes required for implementing the proposed approach.

DEFINITIONS

Planned Activities: all the remaining activities on the Phase Plan including all planned Takt activities, milestones, and constraints identified after performing the make ready process.

Production Labor Activities: a subset of all the planned activities of a phase. The production manager, in collaboration with the team identifies which Planned Activities should be marked for labor tracking.

Standard Work: a statement of all the assumptions regarding the activities that a specific trade must perform as part of a Production Labor Activity. A clear standard work definition ensures consistency when trades provide labor estimates as it defines the conditions of satisfaction for completing those activities.

Budgeted Labor: the estimator's view of the project budgeted labor. It represents the hours, mix rate, and dollars associated with a given production activity as defined in the original project budget, or, the Estimated Maximum Price (EMP). Data captured in the EMP is used to assign applicable cost codes to production activities. When the data does not align with Takt geographic locations (most often it will not due to EMP being set before geographic locations development), the responsible trade project managers will distribute the cost codes to the Takt areas based on their best knowledge of the work.

Estimated Labor: the superintendent's view of the field labor hours required to perform the work. It includes the hours, mix rate, and dollars associated with the Production Labor Activities as defined in the standard work description of the activity. Estimated Labor information is not the same as that of the EMP. It is determined by each responsible trade superintendent after detailed analysis of geographic areas, complexity and method of the work, and Takt plan duration assumptions for pacing the work.

Baseline Labor: a copy of the Estimated Labor after each trade partner completes the Estimated Labor for a phase. It is used for comparative purposes as the trade partners are required to keep the estimated labor for Planned Production Activities up to date in accordance of their best understanding of the remaining work.

Actual Labor: the actual hours spent and the labor mix rate associated with the Production Labor Activities. Actual Labor is provided by each trade partner after the commitment status is updated in the system to reflect that the work has been completed on a weekly work plan.

Remaining Labor: the calculated value of the total of all the estimated labor values for the planned production labor activities of a given phase. It does not include the estimated labor of the completed activities.

Projected Savings or Overage: the calculated difference between the budgeted labor and the total of remaining and actual.

WORKFLOW PROCESSES

Key participants from the project team (project managers, estimators, and superintendents from the various trade partners) collaborated for several weeks to map out the overall process for integrating financial reporting, Takt planning, and labor tracking. The resulting process identifies quality control gates to ensure that the right data is being captured, at the appropriate level of detail, and at the appropriate time.

- For any given phase, and at least six weeks prior to the start of labor tracking, the production manager ensures that the Production Tracker captures all the planned production activities for the phase by creating associations with the existing production activities in the plan. This configures the system with all the planned activities that should be assigned labor hours.
- The production manager schedules a work session with the team to confirm the standard work assumptions for each production activity. This ensures that the team is still in alignment regarding how to estimate or aggregate Estimated Labor information for each activity based on a clear understanding for the work sequence, geographic location, and the conditions of satisfaction.
- At least four weeks prior to the planned start date of a phase each trade partner's project manager reviews their budgeted labor hours and inputs the budgeted labor hours and mix rates in Production Tracker in accordance with the budgeted amounts of the Estimated Maximum Price (EMP). This step allocates the appropriate budgeted labor hours in the system according to the estimator's view of the work.
- Two weeks prior to the planned start of a phase, each trade partner enters the estimated labor hours and crew mix rates in the Production Tracker tool based on his or her best understanding of the effort required to perform the work in those specific locations in accordance to the standard work definitions. This step sets the Forecast Labor information based on the Last Planner's view of the work.

One week prior to the start of a phase, the Production Manager reviews the information for completeness and locks the estimated labor to set the baseline estimated hours and labor mix rates based on the trade partner data. This establishes the Forecast Labor Baseline in the system for comparative purposes.

No later than one week after Production Labor Activities are marked completed as a result of the LPS Weekly Work Planning (WWP) process(i.e., 100% of work done in one area), each trade partner inputs the actual hours for their completed activities. It is important to note, that the system automatically reflects the status of the WWP tasks in the production tracker. This ensures that completed labor hours can only be associated with completed activities on the WWP.

On an ongoing basis, trade partners keep their remaining estimated hours up to date in accordance with their best understanding of the field labor hours required to complete the work in each Takt area.

The Production Tracker tool automatically aggregates the data into visual report graphs that are configured to budgeted, actuals, remaining as well as projected savings or overages. Figure 1 shows a summary view of labor hours by floor. Figure 2 shows a detailed view of the same information organized by floor and then grouped by Takt area for a more detailed analysis. As the STL team implemented this process, they focused primarily on field labor hours. Reporting on crew mix rates and actuals was not always required.

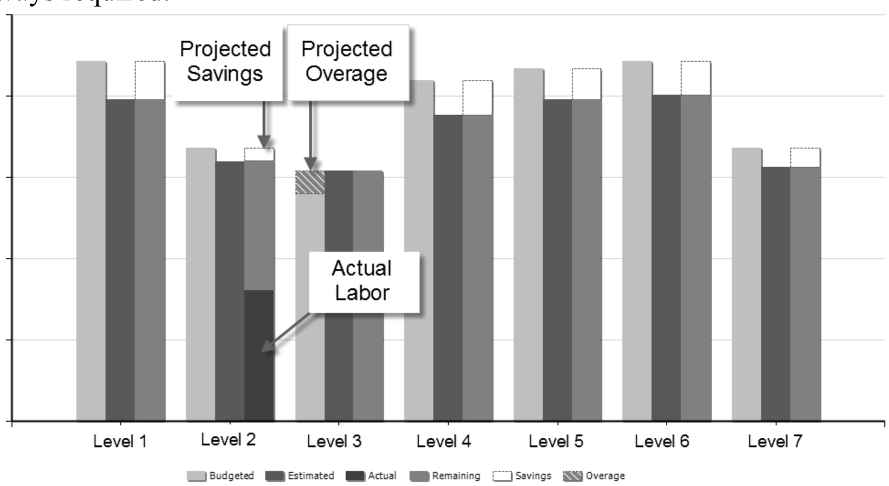

Figure 1 Labor Tracking for a Phase Summarized by Floor

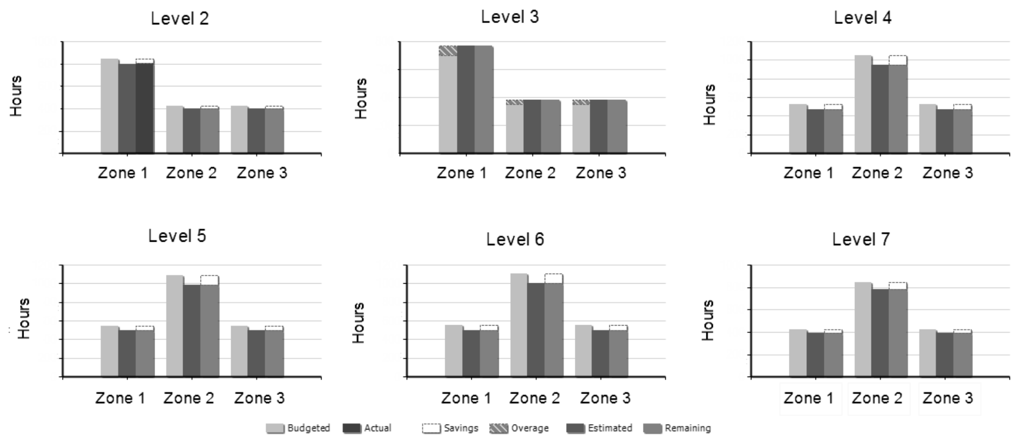

Figure 2 Detailed View by Floor and Takt Area of the Data Shown Figure 1

Review Cycle

The close alignment of data collected from following the TTP and LPS processes and the proposed systematic tracking of labor hours associated with those same activities provides rapid feedback on how resource utilization aligns with planned and completed activities and how weekly work execution planning aligns with the overall project budget.

An integrated team comprised of representatives of the at-risk partners reviews the Production Tracker charts on a bi-weekly basis during the production tracking meetings. Each trade reports on their production tracking graphs. They overview production progress, bring forth challenges, and discuss improvement ideas. These discussions spur many useful suggestions from one trade to another and allows early adjustments of the production plan to improve the overall production flow efficiency.

For example, in many instances, the trades would propose solutions where one trade will make a sacrifice (i.e. spend more labor hours) to increase the production efficiency for several other trades to yield an overall saving for the phase. The financial forecasting team reviews the same rolled up information on a monthly basis and correlates labor assumptions with overall budget forecasting.

Managing Labor Risk

The alignment of field labor estimated hours with Takt geographic locations makes it possible for the various teams responsible for planning and delivering the Takt phases to better manage their risk and maintain alignment with the overall budget targets. Overages by certain risk-reward participants are often offset by savings by other Risk-Reward participants with a net savings to the at-risk work in the phase. For example, when the approach was first applied to the early slab pours, the team immediately identified areas of potential improvement and implemented counter measures to mitigate the risk including, among other things, improved management of crane time.

This approach frees the overall project management team to focus on issues that impact the overall project while making it possible for each phase team to manage the risks within their production phases in alignment with the overall budget against clearly stated targets.

CHALLENGES AND LESSONS LEARNED

CHALLENGING ESTABLISHED NORMS

When the concept of field labor tracking was first introduced to the project team, many were reluctant to participate out of concern that the effort would be redundant since each trade already tracks their field labor in great detail. However, the close examination of the current state revealed that while each trade tracks their own field labor, the tracking was not consistent across the trade partners, performed at different times, and it was not in alignment with the Takt geographic locations. This meant that the at-risk partners would not know the overall shared risk until many months after the work has been completed. Thus limiting their ability to manage that risk in any meaningful way. The review of the future state revealed that this new approach presented a significant benefit to everyone. In addition, it was noted that this approach would improve the transparency, consistency, and alignment of the data across each project phase and thus improve ownership and trust.

PROACTIVE MANAGEMENT VS PASSIVE MANAGEMENT

Field labor estimates are not typically aligned with TTP and LPS processes. The team made the commitment to estimate in accordance with production areas, and, to have the superintendents directly responsible for managing the performance of the work produce those estimates. In other words, Estimated Labor would not be simply a percent of the budgeted hours distributed over geographic areas. This is important to build a sense of ownership of the proposed estimates and also to ensure that the reporting captures the most up to date understanding of the work in accordance with the definitions of standard work within a Takt geographic location.

Generally, current labor tracking practices do not involve setting targets or tracking by production area. The estimator's quantity take-offs used to set the budget targets are performed much earlier in the project and prior to the completion of the Takt planning. The production team executes the work based on the needs of the site and in accordance with the Takt plan. Without the proactive updating of the estimated values, it would be very difficult to have an accurate forecast on what will take place in the field vs. what actually took place. Traditionally, this contributes to the long lag between budgeting and work execution and results in surprises during monthly financial meetings held months after the work has been completed. Thus limiting the team's ability to re-plan and manage this risk and left with the only option of recording such items, each time, as lessons learned to avoid on the next project purposes.

GO-BACK WORK

Go-back work is a general term that describes new activities associated with previously completed production activities where a trade partner has to go back and perform unplanned work in the form of rework or to complete certain tasks within the standard work of a completed Takt area that could not be completed due emerging constraints and that are not significant enough to interrupt production flow. Assumptions about go-back work are often included in the estimated activity duration and labor estimates. Go-back work contributes, to a large extent, to the common budget reporting issue when the cost codes show that 95% of the work is complete but the last 5% is the most costly. Without clear documentation of go-back work, the team would be at risk of making inaccurate forecast assumptions and this poses a risk to a project.

Once go-back work was identified as a risk factor, the team collaborated and identified a plan to mitigate that risk. This resulted not only in improvements to the field labor tracking process, but also in improvements to the standard processes of TTP and LPS. A new activity status, namely Completed with Go-back Work, was introduced and implemented into the commitment cycle. During weekly work planning, the team was asked to apply the new status code to any activity that requires go-back work and record all the known go-back work against the completed activity. Both the original activity and the go-back work itself are tagged with special codes so that they can be identified later for labor tracking and process improvement efforts as increasing trends of go-back work could be a symptom of larger quality issues.

This new process helps the team to keep go-back work very transparent and allows the superintendent/foreman to assign estimated hours for go-back activities, not as percentage of budgeted but actually estimating labor hours considering the go-back strategy. This results in an accurate forecast for go-back work and improved risk management.

CONCLUSIONS

This paper presented a framework for aligning field labor hours tracking with the processes of TTP and LPS. This approach improves current practices. It presents an integrated process that increases the consistency and accuracy of the data and the efficiency by which the data is managed. The approach resolves many of the issues that teams face in practice due the complexities of incompatible reporting tools, methods, and processes which make it impractical to perform any type of integration or analysis on the data.

The implementation of the proposed approach on the STL pilot proved effective and allowed the team to maintain the information across the various phases of production planning in alignment with the overall project budget. It promoted transparency and provided an improved process for managing field labor risk especially in IPD projects where there are shared risk and reward arrangements. Moreover, the simplicity of the approach makes it more likely to be implemented on future projects and improved.

Future improvements on the approach would entail more attention to the tracking of quantities within the Takt areas. The systematic tracking of field labor hours, across Takt geographic locations, and the statement of clear standard work definitions, when augmented with reasonably accurate quantities would serve the basis for building a robust knowledge base for measuring the effect of Takt and LPS on labor productivity. While the current implementation allowed for rudimentary tracking of area quantities, additional work remains to be done to improve material quantity tracking and analysis.

While the focus of this paper has been on the tracking of field labor hours for Takt activities, the approach could be extended along similar lines to other types of production work including that of fabrication, materials, design and pre-construction activities and to improve resource planning at the supply chain level.

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EFFECTS OF LEAN WORK ORGANIZATION AND INDUSTRIALIZATION ON WORKFLOW AND PRODUCTIVE TIME IN HOUSING RENOVATION PROJECTS

Ruben Vrijhoef[1]

ABSTRACT

This paper presents work aimed at improved organization and performance of production in housing renovation projects. The purpose is to explore and demonstrate the potential of lean work organization and industrialized product technology to improve workflow and productive time.

The research included selected case studies that have been found to implement lean work organization and industrialized product technology in an experimental setting. Adjustments to the work organization and construction technology have been implemented on site. The effects of the adjustments have been measured and were reviewed with operatives and managers. The data have been collected and analyzed, in comparison to traditional settings.

Two projects were studied. The first case implied am application of lean work organization in which labor was reorganized redistributing and balancing operations among operatives of different trades. In the second case industrialized solution for prefabricated installation of prefabricated roofs. In both cases the labor productivity increased substantially compared to traditional situations. Although the limited number of cases, both situations appeared to be representative for other housing projects. This has led to conclusions extrapolated from both cases applicable to other projects, and contribution to the knowledge to improve production in construction.

KEYWORDS

Lean methods, productive time, workflow, housing renovation, industrialization.

INTRODUCTION

In construction, particularly housing, clients and builders are searching for solutions for fast and productive working to decrease cost levels. Particularly renovation projects have been found a target area. Various clients such as housing associations and contractors have been experimenting with lean work organization and industrialized renovation concepts. Innovative methods are not just applied to lower costs of renovation but also lean working, process optimization and industrialization

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are aimed at changing the work and mentality of workers to lower the costs (Höök, 2008). The lean aim is a balanced improvement that affects both the product, work organization and the attitudes of workers.

ISSUES OF WORKFLOW AND PRODUCTIVE TIME

LEAN PRINCIPLES OF PRODUCTION AND WORKFLOW

Construction has been characterized by a high number of non-value adding activities, which results in low productivity (Koskela, 1992). According to Botero et al. (2004), construction companies are among the least performing industries due to its lack of effectiveness and productivity. Sometimes these problems are caused by design errors and lack of specifications. Other sources are design modifications during the construction process, lack of supervision on workers, overcrowding of workers, high labor turnover and poor industrial safety conditions (Loera, et al. 2013).

These factors lead to disorganized work and hampered workflow, high rates of accidents, inadequate distribution of materials, equipment and tools, re-work activities, cost overruns and late delivery of projects (Jarkas, 2010).

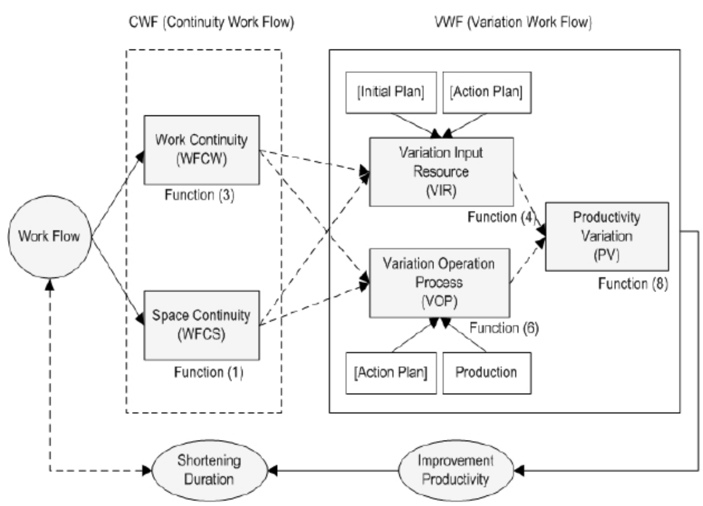

Figure 1. Relation between Work Flow Variation and Productivity (Chun & Cho, 2015).

Variation in work flow influences construction productivity and duration (Chun & Cho, 2015) (figure 1). When there is continuity of workflow, there is a reduction of variation in input resources through continuous work and improvement of productivity and learning effects (Chun & Cho, 2015). Workflow variations thus influence production and productivity.

This impacts largely the efficiency of construction labor. Construction labor costs typically represent 30% to 50% of the total project costs in most countries (Jarkas, 2010). Therefore productivity is an important target to improve efficiency and performance in construction. However roughly 40%-60% of working hours are actually spent on work, and thus 60-40% of working hours would be unproductive (Forbes, et al. 2010). According to Jarkas, (2010) various causes for this can be pointed out, including lacking skills, shortage of materials, dysfunctional communication between site management and labor force, lack of site managers' leadership capabilities and weather conditions.

VIEWS ON PRODUCTIVITY AND PRODUCTIVE TIME

There is no agreement about the precise definition of productivity (Yi & Chan, 2014). The definitions differ in which elements productivity includes and they differ in what is meant by high productivity. Economists and accountants define productivity as the ratio between total input of resources and total output of product. Resource input includes the elements labor, materials, equipment, and overhead (Hanna, Taylor & Sullivan, 2005).

Productivity has been defined as "the power of being productive", "efficiency" and "the rate at which goods are produced" (Yi & Chan, 2014). While the construction industry is a labor-intensive industry, the workforce is the dominant production factor, and according to this, the construction productivity is primarily dependent on human effort and performance (Jarkas, 2010).

Labor productivity issues are a great challenge confronted by many construction firms. Indeed it has been lower than that for other industries; for example in United States construction productivity increased between 1966 and 2003 by only 0.78% per year (Forbes, 2010).

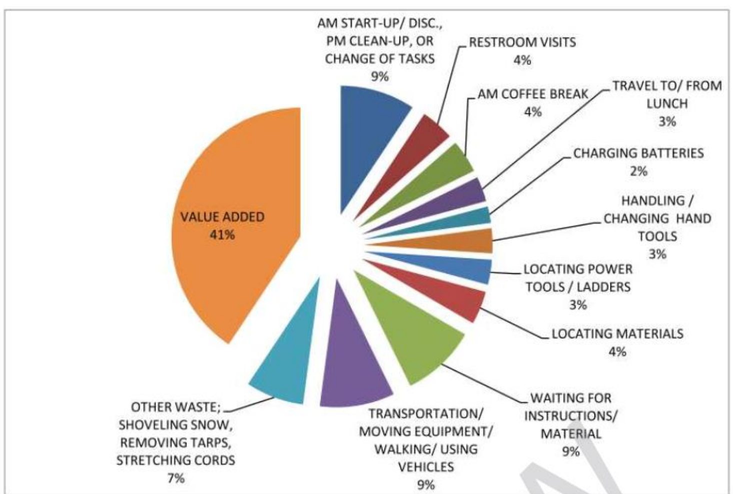

Figure 2: Value-added versus Non-value added activities in a typical workday (Asmar, 2012)

Only about 40% of time spent by workers in a typical workday is value added and more than 50% is wasted (figure 2). Waste is defined as 'anything that is not required to create value for the client or end-user' (Mossman, 2009). Waste is also including: transportation, overproduction, waiting time, inventories, too much machining, moving, and making defective parts and products (Koskela, 1992). Waste and non-value adding activities must be regarded as unnecessary costs (Aziz & Hafez, 2013).

ASPECTS OF WORK ORGANISATION AFFECTING LABOR PRODUCTIVITY

Previous studies differ in explaining how productivity if influenced (Park, Thomas, & Tucker, 2005). Nasirzadeh and Nojedehi (2012) have found groups of causal relations affecting factors of labor productivity such as lack of working area, skillfulness and project management efficiency (Figure 3) (Nasirzadeh & Nojedehi, 2012).

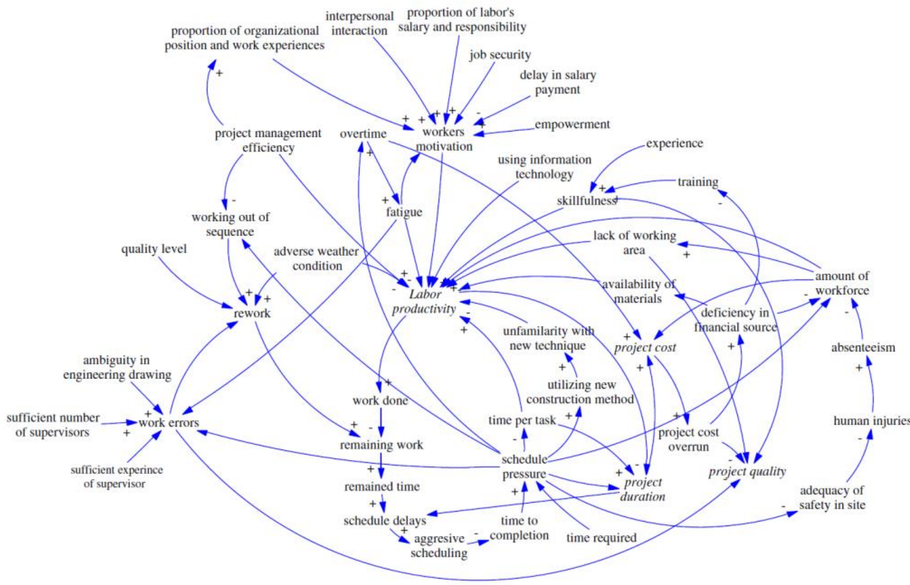

Figure 3:Conceptual model of causes of increased or decreased labor productivity (Nasirzadeh & Nojedehi, 2012).

These influences on labor productivity represent aspects of work organization and could be categorized in three groups (Shehata & El-Gohary, 2011):

- Industry related factors such as complexity and repetition of design, laws and regulations, job duration, work size and type, weather conditions, site location.
- Management related factors such as planning and scheduling, leadership, motivations and communication.
- Labor related factors such as labor skill, motivation and labor availability.

LEAN METHODS AND INDUSTRIALISATION AS POTENTIONAL SOLUTIONS TO IMPROVE PRODUCTION

Workflow, productive time and productivity can be influenced by lean methods and industrialization. In fact, various lean methods particularly aim at these aspects, and so do aspects of industrialization.

AIMS AND EFFECTS OF SELECTED LEAN METHODS

In this study a selection of lean methods have been applied as interventions to improve production, particularly in case 1 (see below). These include the following lean principles:

1. Continuous Flow. Work-in-process smoothly flows through production with minimal (or no) buffers between steps of the process. It eliminates many forms of waste (e.g. inventory, waiting time, and transport). Continuous flow is linked to Planning and Production Control. Four aspects are critical in the implementation of continuous flow; stability, interdependence, takt time and work division (Etges, et al. 2012).
2. One piece flow. Components and materials are being processed directly from one work station to the next, and so on, one piece at a time. This means that the product flows through the work stations. Or vice versa, in construction, the activities flow through each product e.g. a house at a time. The construction process is organised in such a way the workmen can proceed and finish their work per house without waiting, and after that they can proceed to the next without delay, following takt time.
3. Heijunka (Level Scheduling). This form of production scheduling purposely produces smaller batches by sequencing (mixing) product variants within the same process. In construction, activities are often rescheduled among workmen and trades in order to achieve balanced workloads per workman pr day, for smooth production, work flowing, without inventory.

AIMS AND EFFECTS OF ASPECTS OF INDUSTRIALIZATION

Further in this study, a selection of aspects of industrialization has been studied and their potential to improve production as well, particularly in case 2 (see below). These include the following aspects:

1. Standardized Work. The industrialised (and standardized) product requires the work to be standardized too. Documented procedures for manufacturing and installing product components on site including the time to complete each task forces operatives to follow the production system. In the production system errors and rework and thus waste have been eliminated.
2. Offsite production and prefabrication. Conditioned work and shielding the production environment increase the progress of work and minimising the part of the work that has to be done on site and thus reducing the chance of disturbance.
3. Quality management and Poka-Yoke (Error Proofing). Industrialization including standardization and prefabrication prevent design and manufacture errors, and prevent operatives of making mistakes because of the intelligence in the design of components and interfaces and connections. The goal is achieving zero defects, and preventing inspection and correction of defects or mistakes in the production.

CASE STUDIES:

METHODOLOGICAL APPROACH TO THE CASE STUDIES

The above lean methods and aspects of industrialization have been applied as interventions and subjects of analysis in two respective case studies. The lean methods have been particularly applied as interventions to improve workflow and productive time in below case 1. The aspects of industrialization and their improvement potential have been studied particularly in case 2 improving workflow and productive time as well (see below).

In both cases the effects on workflow and productive time have been studied in two ways. Records of practical effects have shown the improvement of the workflow. Measurement of numerical effects in the planning in particular have demonstrated the improvement of productive time. Both cases are presented below.

CASE 1: LEAN WORK ORGANIZATION

Case description.

This housing renovation included 69 social rented houses and 30 social rented small apartments. The renovation was commissioned by the client being an housing association. The project consisted of renewing the bathroom, the toilet, the electrical installations and the kitchen.

Application of lean methods

As the project is was demand driven, the inhabitants were asked when they wanted the refurbishment and if they wanted the bathroom and toilet, only one or none, but at the end all the inhabitants decided to refurbish. Additional on the site managers' house there is a space where the inhabitants can go and relax or cook while the refurbishment takes place at their homes.

Further lean tools were applied to multi-skilled teams included transfer of activities between workers, coaching among workers, balancing of work, reallocation of activities, collaboration between workers, just in time delivery, security of materials, autonomous self-controlled teams.

Effects on workflow

The continuous workflow and one-piece-flow approach also included coaching and taking over tasks among trades, so virtually the trades could be 100% productive. For example the first day of refurbishment is done by the demolition workers, who learned some basic electrician tasks to be able to have a whole productive day, so transfer of activities is an important subject for workflow in this project.

Additional the project culture is of collaboration between workers, for instance the plasterer had one extra hour at the end of the day, so he uses it for cleaning and organizing the houses for a smooth workflow the next working day.

The planning of the project was done in a modular way, in which each day they start a new house and the workers know exactly where they are in the planning, what they have to do each day and how the projects is doing.

Effects on productive time

Pull Planning and level scheduling resulted in bathroom renovation taking seven days, the toilet four days and the kitchen five days within those seven days, so in total the renovation of each house took seven working days and in total there are ten workers in the project.

Each day or half day one trade took over all activities of other trades (see below; each color in the bar chart represents a particular trade). This resulted in in "full days" or "full half days" of work for all trades, and less transport, less fragmented work, and less times of preparation of their workplace.

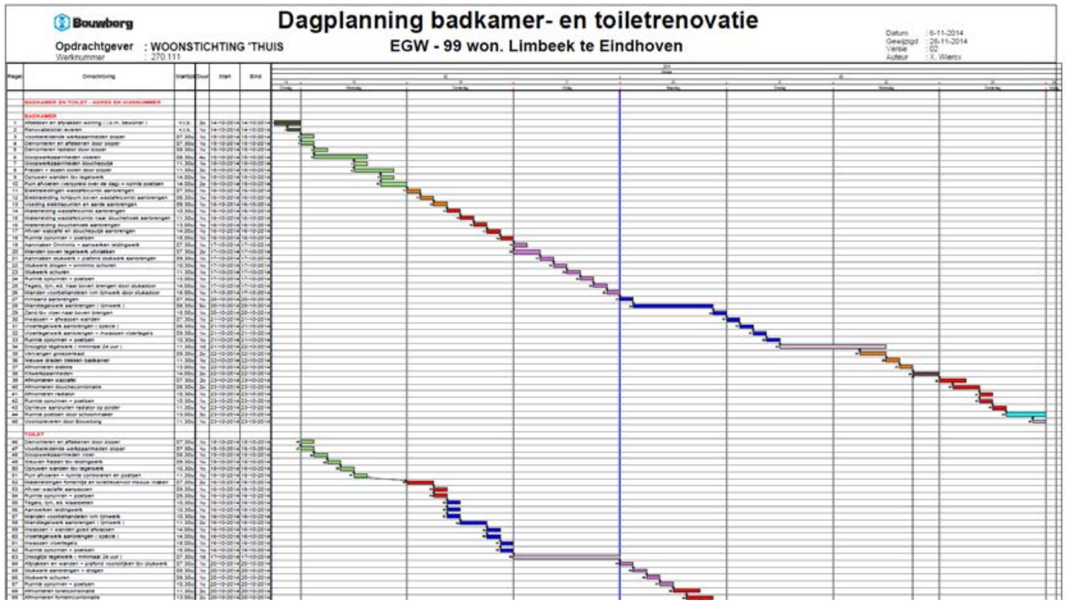

Figure 4: Level scheduling in the project, planning each trade fully productive per day or half day (each color represents a trade per day or half day) (planning in Dutch).

CASE 2: INDUSTRIALIZATION

Case description.

In this case 109 houses were renovated. The industrialization included prefab elements for roofs and façades.

Figure 5: Installing prefabricated roof and façade elements (Sav, 2014).

Aspects of industrialization

This roof and façade system has been fully produced and pre-engineered in a factory allowing to be installed for two houses in one week, including all interior work being done in the same week. The interior work had not been industrialised however.

Effects on workflow

The prefabricated elements and the systematic delivery of elements to site, as well as the high quality level of elements and connections improved workflow and speed of installation of roofs and facades.

To improve the interior workflow as well, the trades worked in multi-skilled teams. Those teams did most of the work in a house with a high level of interdependency and joint coordination. Interviews with the trades revealed several advantages (Mulder, 2016): reduction of disturbance, increase of workers motivation, reduction of schedule pressure, and higher sense of responsibility among workers.

Effect on productive time

Production time analyses of the project showed that the expected renovation time of one house had decreased from traditionally 15.9 days to 5.0 days due to the industrialization efforts. The industrialization of the roof (as well as the façade) also led to a reduction of labor hours needed for the renovation (Table 1).

Table 1: Comparing labor hours between traditional renovation and industrialized renovation of a roof (Berben 2015)

	Task	Traditional renovation	Industrialized renovation
1a	Demolishing roof	7.5	7.5
1b	Preparation prefab roof	0	0.88
2a	Mounting bearing structure	4.72	2.58
2b	Adjustment for prefab roof	0	0.80
3	Mounting roof	13.63	3.26
4	Mounting gables	5.28	2.13
5a	Fitting sheet	0	1.68
5b	Waterproofing	0	1.38
	Labor hours on site	31.13	20.21
	(Pre)fabrication hours wood work	0.17	0
	(Pre)fabrication hours roofing sheets	1.0	0
	Prefabrication hours roof	33	16
	Total	64.30	36.21

Case study comparison and combination

In the first case the production and productivity improvement have been based on lean work organization and aimed at interior work. In the second case the production and productivity improvement have increased spectacularly by prefabricating the roofs and façades, and partly due to altering work organization. This increase can be explained largely by the prefabrication of the product, influencing factors such as work speed, error proofing and standardization.

In addition to the lean work organization particularly the multi-skilled teams delivered several advantages leading to increased labor productivity. However interestingly enough the second case did not deliver such evidence that working with multi-skilled teams on the industrialized concept this would not necessarily lead to increased labor productivity. Further research has to show in what situations and under what conditions working in multi-skilled teams will increase labor productivity.

Both cases of this paper have showed different as well as same kind of effects and aspects of improved and lean work organization, while the second case was aimed at product industrialization primarily, this case also showed evidence of additional lean methods applied. The effect on workflow and productive time for the interior of the renovations were comparable too. The effect on productive time for the exterior work (roof and façade) was obviously different in both cases while in case 1 this was not part of the work, nor was an industrial approach part of the renovation. However if the exterior had been part of the renovation in case 1 this would have been combinable in this case too probably, as applied in case 2.

DISCUSSION AND CONCLUSIONS

Applications of lean work organisation and industrialization appear to have their effects on workflow and productive time. Although these are advancements in their own right they do not automatically point towards each other nor always combine in construction practice. However in theory both concept of lean and industrialization, and the routes they both suggest towards smoother workflows and reduced productive time, and increased productivity, are often part of the same conceptualisations of either lean construction or industrialized construction. In theory they are quite interconnected.

Both concepts could be rejoined into one probably, if this would be based in the same kind of effects and aims both have. Because apparently both concepts have taken another route towards the same effects and aims. This would strengthen both concepts, in practice as well as conceptually and theoretically, and their effect on such issues as workflow and productivity as discussed in this paper.

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A NEW MODEL FOR CONSTRUCTION MATERIAL LOGISTICS: FROM LOCAL OPTIMIZATION OF LOGISTICS TOWARDS GLOBAL OPTIMIZATION OF ON-SITE PRODUCTION SYSTEM

Olli Seppänen[1] and Antti Peltokorpi[2]

ABSTRACT

Research on construction on-site material logistics has mainly concentrated on how to best deliver materials on site or how to store the materials in constrained space. Less research has been done on the impact of logistics on labor productivity. The purpose of this research was to review empirical results related to logistics and labor productivity reported in literature as well as previous research on construction material logistics to come up with requirements of a new lean model for material logistics. Current research on construction logistics was found to focus on part of the problem and to offer partial solutions rather than globally optimize the production system. Indirect costs of logistics causing interference to other tasks or waste due to material transportation have not been extensively discussed but several empirical results can be potentially explained by logistics even though the research was not about logistics. The paper proposes a new model for construction material logistics and hypotheses to be evaluated in future empirical research or simulation studies. The paper is valuable for academics with research interests in construction logistics or productivity areas and for practitioners seeking productivity improvements.

KEYWORDS

Lean construction, logistics, inventory control, productivity.

INTRODUCTION

Logistics accounts for a large part of the total cost of a construction project. In contrast with other industries most of the money is spent on site, handling material as opposed to transportation outside the project (Elfving et al. 2010). This makes on-site logistics a very important improvement area for contractors. Most attention has been given to congested projects with limited site storage possibilities. Interestingly, despite the challenge of space, the direct observation of authors on several projects with limited storage space, echoed with Mossman's (2007) observations, indicate that production planning is better done on tight sites which results in an overall

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improvement in the process. We do not know if this is because logistics is critical for the performance of on-site production system, better planning of logistics requires more from other planning aspects or better teams are selected for difficult projects.

Motivated by these observations we set out to review what research results have been reported for various aspects of logistics. Our goal was to identify all the relevant aspects of on-site production system from logistics points of view and review empirical evidence to identify what we know and which aspects have been ignored by research. Our hypothesis was that logistics research has been based on single case studies and each study focuses only on small part of the problem. In particular, we thought that most of the logistics research focuses on the cost of logistics or delivery reliability and ignore aspects tied to labor productivity, for example due to interference or carrying materials by skilled labor.

METHODS

A literature review was performed related to construction logistics and empirical research on productivity. A search was performed in Google Scholar with keywords “Construction logistics” and “Construction project productivity empirical research” and the first 15 pages of hits were considered for relevance. Additionally IGLC database was searched with keywords “logistics” and “productivity”. The abstracts of all found papers were reviewed to evaluate their relevance and the full paper was reviewed if the abstract was relevant. A logistics paper was deemed relevant if it was clearly related to construction logistics. A productivity paper was deemed relevant if it included empirical data, which was somehow collected on field. In total, 26 logistics related papers and 22 empirical productivity related papers were reviewed in full.

The logistics literature was categorized based on problem statement (i.e. how the problem of construction logistics was formulated) and the proposed solutions (if any). The categories were used to formulate an overall model of logistics based on constructive research principles. Empirical results related to productivity were then analysed related to the logistics model to identify gaps in knowledge. Finally, research questions were proposed to address these gaps.

LITERATURE REVIEW

CONSTRUCTION LOGISTICS PROBLEM STATEMENT

Logistics was approached from several different viewpoints. Table 1 shows the list of papers and the viewpoints they chose for logistics. Most papers considered three or four viewpoints simultaneously (11 papers). There were very few attempts to discuss logistics broadly. However, Mossman’s (2007) paper is an important exception and was an attempt to highlight several important aspects of logistics.

Table 1: Logistics viewpoint of different papers

Authors	Logistics viewpoint									
	Costs	Inventory	On-time delivery	Storage location	Transport equipment/distance	Interference	Queue of transport vehicles	Supplier's viewpoint	Impact of design	Satisfaction
Arbulu & Ballard (2004)		x	x							
Arbulu et al (2005)	x	x		x						
Bertelsen & Nieslen (1997)	x		x							
Bortolini et al. (2015)		x		x						
Caron, Marchet & Perego (1998)	x		x							
Cheng & Kumar (2015)			x	x						
Elfving et al. (2010)				x	x					
Hamzeh et al. (2007)			x							
Ibrahim & Hamzeh (2015)					x				x	
Jang, Russell & Yi (2003)										x
Kalsaas et al. (2011)	x			x	x					
Lange & Schilling (2015)			x	x	x					
Mossman (2007)	x	x	x	x		x			x	
Ng, Shi & Fang (2009)		x	x		x		x			
Nguyen et al (2008)								x		
Pinho, Telhada & Carvalho (2008)	x	x								
Said & El-Rayes (2013)	x			x	x					
Said & El-Rayes (2014)	x			x		x				
Salagnac & Yacine (1999)	x		x					x		
Silva & Cardoso (1999)	x	x	x							
Skjelbred, Fossheim & Drevland (2015)			x			x	x		x	
Sobotka & Czamigowska (2005)	x	x								
Vidalakis, Tookey & Sommerville (2011a)	x	x						x		
Vidalikis, Tookey & Somerville (2011b)								x		
Voigtmann & Bargstädt (2010)				x	x	x				
Wegelius-Lehtonen, T (2001)	x									

Decreasing the cost of logistics from the point of view of contractors was the most common viewpoint. Logistics cause extra costs which are not related to transportation if materials are not on site when required, materials are incorrect or if there are large amounts of materials on site which tie up capital (Arbulu et al. 2005). Costs can also increase due to wasted labor because workers are looking for materials and management time is expended to manage inventories and materials can be damaged (Arbulu & Ballard 2004). Wegelius-Lehtonen (2001) focused on performance measurement of logistics, calling for process metrics. For example, purchase price is not a good metric because buying in bulk may lead to lower unit price but ignores the cost of logistics.

Decreasing inventories was highlighted especially in congested projects (Mossman 2007; Said & El-Rayes 2013; Said & El-Rayes 2014). Importantly, Mossman (2007) noted that projects with congested sites require detailed planning of logistics and it seems that these projects go better in other respects as well. Obviously inventories and material buffers are against the lean philosophy and this angle has been adopted in several papers (Arbulu & Ballard 2004; Arbulu et al. 2005). However, sizing inventory is a matter of balancing customer service level with total logistics cost (Silva & Cardoso 1999).

Inventory is tied to on-time delivery of materials. Caron, Marchet and Perego (1998) investigated the optimal material buffer to achieve a desired level of protection against material shortages. On-time deliveries are at risk when deliveries are done by each subcontractor trade (Lange & Schilling 2015) and by the truckload (Bertelsen & Nielsen 1997). In this respect, the suppliers have a very different optimization problem. For example, Builders' Merchants are supplying materials for several construction sites and hold contingency inventories for a large number of contractors. (Vidalikis, Tookey & Sommerville 2011a). They lose money if they do not optimize the use of their transportation capacity. It does not make sense for them to move to Just-in-Time delivery because they need full trucks and minimized distances to stay profitable (Vidalikis, Tookey & Sommerville 2011b). Several case studies of Make-to-Order producers highlight that the suppliers minimize their cost by producing one type of element in long runs and shipping the materials by type (or size) (Salagnac & Yacine 1999; Nguyen et al 2008). These results highlight the conflicting goals of various actors in supply chain.

Logistics can also be viewed from the waste point of view. Waste can result from incorrect offloading resources (Elfving et al. 2010), moving material several times (Elfving et al. 2010; Voigtmann & Bargstädt 2010) and interference of storage areas with work (Voigtmann & Bargstädt 2010; Said & El-Rayes 2014). The distance of storage area to work area is an important source of waste due to horizontal transportation often done by skilled labor (e.g. Elfving et al. 2010; Ng, Shi & Fang 2009; Said & El-Rayes 2014).

LOGISTICS SOLUTIONS IN LITERATURE

To tackle the various logistics problems in construction, a wide variety of solutions have been proposed in literature. Table 2 presents an attempt to categorize the solutions. Centralized logistics centers, typically including kitting, were the most commonly proposed solution. Authors pointed to the need of improved scheduling and to Just-in-time deliveries. Digital tools including simulation or optimization, web-based system for logistics or solutions based on Building Information Modeling were often proposed. Other solutions included using a separate logistics company, increased standardization or pre-assembly and methods to size the material inventory or safety stock optimally.

Logistics centers in construction can support multiple logistics functions, such as storage, transport, distribution and kitting (Hamzeh et al. 2007). They make possible just-in-time deliveries to construction sites and buffer against variability in activity start dates and durations (e.g. Arbulu and Ballard 2004). A great opportunity given by logistics centers is the ability to prepare location-specific delivery packages (kits) which can be delivered to the point of installation to increase productivity (Elfving et al. 2010).

Several authors have proposed improved scheduling or production control as a counter-measure. For example, several authors from the lean community (e.g. Arbulu & Ballard 2004; Arbulu et al. 2005; Mossman 2007) call for the use of Last Planner System to make sure that all the prerequisites meet at the right time. Other approaches involving scheduling include optimizing start dates of tasks within their total float so that space is allocated to interior storage areas which are in turn optimized based on space constraints and proximity to work (Said & El-Rayes 2014).

Table 2: Logistics solutions categorized based on literature

Authors	Logistics solution									
	Centralized logistics / logistics centers / kitting	Kanban / Just-in-Time	Improved scheduling / LPS	Buffers / safety stock	BIM-based solutions	Simulation-based solutions / optimization	Web-based logistics software	Standardization / pre-assembly	Logistics company	Other
Arbulu & Ballard (2004)	x	x	x				x	x		
Arbulu et al (2005)		x	x				x			
Bertelsen & Nieslen (1997)	x	x								
Bortolini et al. (2015)					x			x		
Caron, Marchet & Perego (1998)				x						
Cheng & Kumar (2015)					x	x				
Elfving et al. (2010)	x						x			
Hamzeh et al. (2007)	x	x								
Ibrahim & Hamzeh (2015)						x				
Jang, Russell & Yi (2003)										
Kalsaas et al. (2011)	x		x							
Lange & Schilling (2015)							x			
Mossman (2007)			x						x	
Ng, Shi & Fang (2009)		x				x				
Nguyen et al (2008)										x
Pinho, Telhada & Carvalho (2008)	x						x			
Said & El-Rayes (2013)			x		x	x				
Said & El-Rayes (2014)					x	x				
Salagnac & Yacine (1999)									x	
Silva & Cardoso (1999)				x						x
Skjelbred, Fossheim & Drevland (2015)		x	x		x		x		x	
Sobotka & Czarnigowska (2005)	x									
Vidalakis, Tookey & Sommerville (2011a)										x
Vidalikis, Tookey & Somerville (2011b)										x
Voigtmann & Bargstädt (2010)						x				
Wegelius-Lehtonen, T (2001)										x

IT support for logistics was highlighted in some form in most papers. BIM-based approaches either used BIM to evaluate optimum or feasible storage areas (Said & El-Rayes 2013; Said & El-Rayes 2014; Cheng & Kumar 2015) or used BIM for site logistics planning or 4D simulations (Bortolini et al 2015; Skjelbred, Fossheim & Drevland 2015). Simulation or optimization based IT solutions included a wide variety of models, for specific simulation of a structural formwork system (Ibrahim & Hamzeh 2015) to simulating several aspects of logistics (Voigtmann & Bargstädt 2010) to optimizing schedules based on logistics (Said & El-Rayes 2013, 2014). Web-based systems for logistics included delivery management systems (Pinho, Telhada & Carvalho 2008; Elfving et al. 2010; Lange & Schilling 2015; Skjelbred, Foosheim & Drevland 2015) and web-based production control systems linked to material management (Arbulu & Ballard 2004; Arbulu et al. 2005).

Other interventions related to logistics were concerned with optimizing inventories or safety stocks (Caron, Marchet & Perego 1998; Silva & Cardoso 1999), using logistics companies to perform transportation on site (Salagnac & Yacine 1999; Mossman 2007; Skjelbred, Fossheim & Drevland 2015) or using standardization or pre-assembly (Arbulu & Ballard 2004, Bortolini et al. 2015). Ngyuen et al. (2008) proposed a new process-based cost modelling system, including the process cost of logistics. Wegelius-Lehtonen (2001) reviewed a set of performance measurement indicators for different company levels (strategic, tactical, operational). Silva and Cardoso (1999) defined different logistics decisions needed on strategic, structural and operational levels. Vidalakis, Tookey & Sommerville (2011a, 2011b) reported analysis related to Builder's Merchants and their profit drivers.

NEW MODEL OF LOGISTICS AND REVIEW OF EMPIRICAL RESEARCH RESULTS

Based on different formulations of logistics problem and solutions, we propose the model in Figure 1 to guide empirical research. Logistics impacts work flow reliability and labor productivity which are both key labor performance metrics in lean construction. Safety stocks, either on-site or in a logistics center, impact work flow reliability (1). However, safety stocks on site decrease the amount of space available (2). The available space is also impacted by storage locations (7) and other work tasks (9) and impacts labor productivity (8). Storage locations close to work performed interfere with productivity (6) but decrease needs for material transfer (3) which can impact productivity of skilled labor if they are responsible for logistics (4). Location of logistics equipment should be connected to storage locations (10) and affects needs for material transfers (5).

Empirical research results on productivity were classified based on the connections in the model of Figure 1 (Table 3). The table further classifies results based on method: simulation, one or more case studies and whether the evidence for results was anecdotal or empirical (measured). In most cases, productivity was not explicitly measured for each connection but as an aggregate measure and the papers just hypothesized cause and effect in their discussion of results.

Most of the papers focus on the impact of delivery on workflow reliability, for example by classifying lack of materials as a root cause of failed plan completion (e.g. Liu & Ballard 2009) or by directly investigating the impact of safety stocks on productivity (e.g. Gonzalez, Gonzalez & Miller 2011). Horman & Thomas (2005) optimized safety stock size based on not having too much or too little inventory. Watkins et al. (2007) simulated the relationships between multiple crews moving through the building but ignored material stockpiles. A few papers discussed several connections but their evidence was anecdotal in nature (Court et al. 2005; Elfving et al. 2010).

Some connections have gained significantly less attention to others. For example storage location and its direct impact on labor productivity due to skilled labor moving materials was mentioned only in three studies and the evidence was anecdotal (Court et al. 2005) or mixed with other factors (Thomas & Sanvido 2000). The impact of storage locations to availability of space and thus to productivity was mentioned in four papers but papers reporting productivity impacts (Court et al. 2005; Elfving et al. 2010) did not separate these impacts from other factors and their evidence was anecdotal in nature. The interface between storage locations and equipment has not been discussed.

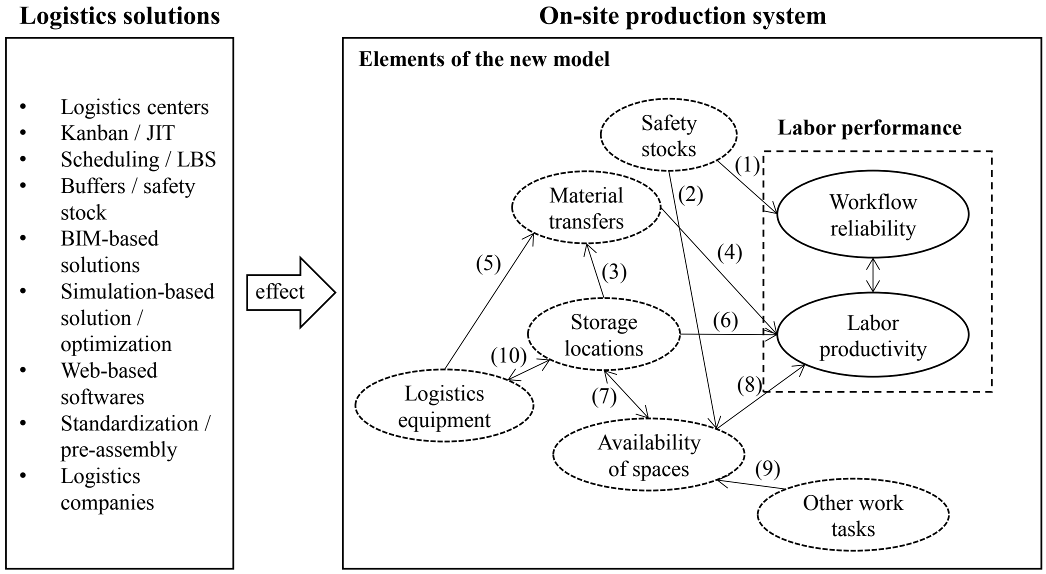

Figure 1: New model of construction on-site logistics

CONCLUSIONS AND FUTURE RESEARCH

Some aspects of logistics, such as delivery reliability, have been extensively studied. Others, such as interference of materials with crews or the impact of storage locations on productivity have received far less attention, confirming our initial hypothesis. Much of the evidence is based on single case studies and several studies are anecdotal in nature. It can be concluded that despite the importance of the topic, we do not know much about the impact of logistics on the performance of production system. We lack tools for making logistics decisions taking into account all the impacted variables.

Future research should focus on filling the gaps of this research in a systematic fashion, for example based on the model presented in this paper. Research should isolate the impact of different factors when possible. For example, the impact of storage location to labor productivity can be isolated by explicitly recording the non-value adding time required to haul materials from storage to installation area. Any interventions and action research should clearly identify which variables they are targeting and their impact should be measured. Simulation can also be a very useful research method.

The limitations of this research include the small amount of search terms used to find literature to review. More relevant papers could be found by using traditional keywords for on-site logistics, for example “materials management”. Regarding productivity, several important papers could be found by searching for the term “waste”. However, it is unlikely that the overall conclusions would change by adding more papers. It is safe to say that research on construction logistics has been very fragmented and a more systematic research approach is required to increase the understanding of this important topic.

Table 3: Empirical results classified by connection

Authors	Method / evidence	Model connections 1	2	3	4	5	6	7	8	9
Bortolini et al. (2015)	Case Study / empirical		x		x	x			x	
Bulhoes, Picchi & Folch (2006)	Two case studies / empirical	x								
Court et al (2005)	Case study / anecdotal		x				x	x	x	x
Elfving et al. (2010)	Case study/ anecdotal		x	x	x			x	x	
Gonzalez, Gonzalez & Miller (2011)	Case Study / empirical	x								
Horman & Thomas (2005)	Three case studies / empirical	x	x						x	
Kalsaas et al. (2011)	Case study / empirical				x					
Lange & Schilling (2015)	Case study / empirical				x			x		
Liu & Ballard (2008)	Case study / empirical	x								
Liu & Ballard (2009)	Case study / empirical	x								
Ng, Shi & Fang (2009)	Case study/ simulation				x					
Nguyen et al (2008)	Simulation				x					
Picard (2002)	Case Study	x								
Pinho, Telhada & Carvalho (2008)	Case study/ anecdotal	x						x		
Skjelbred, Fossheim & Drevland (2015)	Case study/ anecdotal	x			x				x	
Thomas & Sanvido (2000)	Three case studies / empirical	x				x	x			
Voigtmann & Bargstädt (2010)	Simulation	x		x	x		x			
Watkins et al (2007)	Simulation								x	x
Zhao & Chua (2003)	Case study / empirical	x							x	

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ROLE OF LOADING PLANS IN THE CONTROL OF WORK IN PROGRESS FOR ENGINEER-TO-ORDER PREFABRICATED BUILDING SYSTEMS

Guilherme Trevisan[1], Daniela Viana[2], and Carlos Formoso[3]

ABSTRACT

The benefits of pull production systems are well reported in the literature. Some authors argue that those benefits can be achieved through the control of work-in-progress (WIP) levels. However, when the construction project uses Engineered-To-Order (ETO) building systems, each production phase (namely design, fabrication, and site installation) may require a different batch size. The task of reducing batch size become more complex, since the production system needs a systemic view of the project flow. The paper discusses the concept of a pull system, based on the idea of controlling WIP, in a less repetitive environment. Design Science research was the methodological approach adopted in this investigation, in which an empirical study was carried out in partnership with a Steel Fabricator. Several sources of evidence have been used, such as participant observation, semi-structured interviews, document analysis, direct observation, and analysis of existing databases. The study revealed that the definition of the minimum batch in this context must consider both how the assembly process is carried out on site, and also how components are transported. The implementation of a method to control WIP in the plant contributed for reducing lead-times and inventory levels, and made project delivery more reliable

KEYWORDS

Engineer-to-order, work-in progress control, prefabricated building systems.

INTRODUCTION

Different degrees of customization exist for prefabricated components in the construction industry, from nails and bolts that are typically produced by make-to-stock production systems, to complex and highly customized components that are customer-driven manufactured (Elfving et al., 2004). In an engineered-to-order (ETO) product, the customization point is located at the design phase, which means that the design is not started until a client order arrives (Kachru, 2009).

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Due to this close interaction with the client, the ETO production systems results in a dynamic, uncertain and complex environment (Bertrand and Muntslag, 1993). Understanding the peculiarities of this kind of production system is important to conceive planning and control systems that are capable to cope with the high level of complexity involved. Logistics management is a critcal factor in companies that deliver ETO prefabricated components, because it usually requires controling different project phases, such as design, fabrication and assembly, in a multiple project environment. The delivery of each project often affects the others due to the need of sharing resources, while requiring distincts information and raw materials, and demanding different levels of interaction with the client. In the construction industry, ETO prefabricated building systems have an extra difficulty: the final assembly needs to be carried out in a constuction site. This often means that there is a complex interaction between building subsystems, delivered by separate companies. Moreover, each project has its own requirements for loading and must be delivered in different location and in different site conditions.

In some ETO suppliers for the construction industry, planning and control are normally carried out by each production phase (design, manufacturing, logistics and assembly) as isolated and disconnected processes, increasing the project lead time (Elfving et al., 2004). The fragmentation and suboptimization of each production phase tend to affect the downstream flow, making the assembly less reliable due to delays in the delivery of components, and also to the need solve problems related to the poor integration of components (Tommelein, 1998). It is common to have the construction sequence being defined by the fabrication process with the aim of freight optimization, resulting in large production batches (Matt et al., 2014). Process transparency is necessary between manufacturing and assembly processes, in order to make the former understand the needs of the different projects and plan better its production based on a confirmed demand (Čuš-Babič et al., 2014).

Logistics management plays a key role in this environment (Hicks et al., 2001). A delay on delivering components on the site causes an increase on the assembly time and can result in contract penalties, while the early expedition of deliveries increase the storage cost, and handling components efforts on site, affecting company profits (Čuš-Babič et al., 2014).

This investigation is part of a broader research project on logistics management, developed in partnership with a company that designs, fabricates and assembles steel building systems on site. Steel building systems typically involve a large number of components, and some of them need to be preassembled on site. Each batch required a wide variety of heavy components to be fabricated, or bought and delivered at the same time to the construction site.

Ronen (1992) claims for a complete kit of products to start the production, without which there will be different problems such as an increase on work-in-progress (WIP) levels, on lead time, problems of quality and rework. In ETO environments, it must be considered that there are different project stages (design, fabrication, logistics and assembly) and the focus should be on producing complete kits in all those stages, considering the requirements of the downstream process. In order to adopt a pull production strategy for fabricating or designing according to the site needs, there is a need to consider those factors. The adaptation of the pull-system for non-repetitive and complex production environments should be based on the WIP control. For Hopp and Spearman (2004), controlling a low-level of WIP brings most of the benefits of a pull-system. The aim of this paper is to presents the preliminary results of an investigation which aims to devise a method for controlling work-in-progress in ETO prefabricated building systems, through the discussion of the loading plans role in controlling WIP.

RESEARCH METHOD

Design Science Research was the methodological approach adopted in this investigation. This approach is concerned with devising artefacts that serve human purposes, such as methods, models, and guidelines (Van Aken, 2004). The design science is understood as a model of knowledge production, and the action research as one of the possible ways to achieve this type of knowledge production. Cole et al. (Cole et al., 2005) highlight the synergies between both approaches and argue that design science research benefit from the mature body of evaluation and other criteria of performing action research.

The research process was divided in three main parts. The first consists of understanding the existing situation of the company, which has been involved in research projects with the Federal University since 2011. The second part refers to the implementation process, in which different cycles for devising, implementing, and evaluating a solution took place. The third part refers to the development of the final method, which is out of the scope of this paper.

The implementation process lasted 8 months, when the main researcher made weekly visits to the company. A wide range of sources of evidence have been used during this period, such as semi-structured interviews, document analysis, participant observation, direct observation, and analysis of existing databases. The implementation process was made possible thanks to the participation of the manager of the logistics department, who were willing to make some structural changes in the company processes. For this reason, the implementation process was based on action-research, to collaboratively develop the solutions.

The analysed company is the largest steel fabricator in Brazil: it had more than 2000 workers, three manufacturing plants, around 200 simultaneous contracts, and an annual revenue around $300 million dollars. It is divided into three different business units: (a) light steel structural systems for warehouse and industrial buildings; (b) high rise buildings; and (c) heavy structures for bridges and off-shore platforms. This study is focused on the operations of the first one. The main production processes under the scope of the company are the design and engineering of components, fabrication, and site assembly of steel building systems.

RESULTS

EXISTING SITUATION

Since 2006, the main director of the first business unit has started to lead a program for implementing lean production concepts and methods throughout the company. One of the most important changes made in the company as a result of that program was the reduction of batch size, by dividing a project into stages. Each stage is also broken into sub-stages, which contains a set of specific products that can be assembled independently. The aim was to control design and fabrication based on those sub-stages, after the conceptual design is approved by the client. The manufacturing plant has a lower level of control, which was called packing-list (PL). PL is a set of similar materials that can be put in sequence in a machine to be produced – it is a subdivision of sub-stages for fabrication reasons. As the sub-stage is a batch configured for assembly needs, it will be called as assembly batch.

One important characteristic of the contracts, which affects the planning and control system, is the payment conditions. In general, when a project is sold, a deposit of around 7% is required. The second payment, is made when the materials are shipped to the construction site summing up 75% of the project, paid according to the amount of materials delivered. The remaining 25% is paid as long as the stages are assembled in the construction site. This contractual rule creates an incentive for the company to increase work-in-progress, by producing the heavier components first, although it is the final building that is sold to the client. While the division in stages and the establishment of an assembly batch for all production phases were important steps toward a focus on the final product, the production phases were still encouraged to produce in volume.

Despite the decision of dividing project into stages, the most important metrics currently used for different production phases were based on the weight of components designed, produced, transported and assembled, leading to a strong focus on the utilization of capacity. However, the nature of each production phase requires a different batch for production (Figure 3), which means that each phase would improve weight metrics differently. The establishment of an assembly batch was an attempt to standardize those differences, making the company as a whole to consider the demands of the final production phase. The assembly batch should work as a transfer batch, with the aim of reducing work in progress.

The output of the design development phase was the project as a whole, except in the case of large projects in which drawings could be delivered as a package for each building. The detail design refers to the detailing of each steel component, so each team used to work in a specific set of products of the project, such as structural elements, roofs, and closing elements, including all the components required for the assembly of those products.

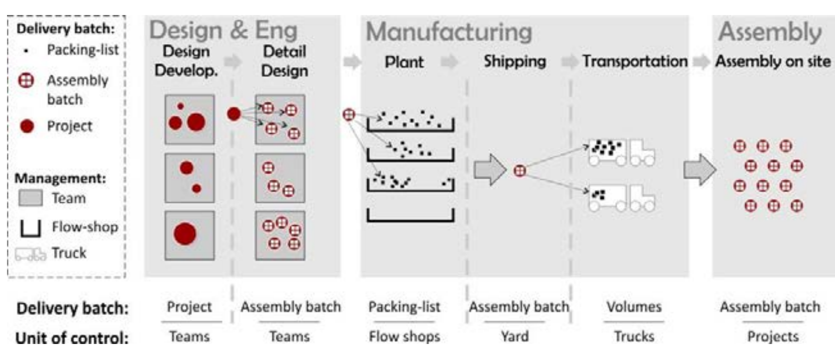

Figure 3. Different batching processes

The fabrication plant, in turn, was divided in flow shops specialized in one or a small set of product types. For that reason, each batch was divided into packing lists. Different packing lists from the same assembly batch should be produced by different flow shops. The production planning and control system of the plant used to be based on the maximum utilization of capacity. Therefore, the plant manager would rather put similar PLs from different projects in sequence, instead of sequencing different PLs from the same project in order to finish it earlier.

The plant yard used to receive the ready components, which could be organized in individually or in a package of components, depending on the size. At that moment, the products were organized in the yard according to the product type to wait the completion of the assembly batch. After the assembly batch is manufactured, the shipment process is able to start. However, in most cases, it is not possible to ship a complete assembly batch in one truck. For that reason, in the loading process, components are organized according to the package made after production. Lastly, at the construction site each truck load should wait for the completion of the batch delivery before starting the assembly process. Deliveries and measurements at this phase are based on the assembly batch completion.

All those different batches, associated with the incentive on weight metrics were causing high levels of inventories at the plant yard and at the construction sites. The shipment department manager would struggle to send any fabricated component, regardless if it was from a complete batch or not. This practice was leading to material handling challenges, making it hard for the site manager to know if everything required for the assembly process was already there. Therefore, the company's director implemented a rule in the ERP system that would avoid shipping components from a not fully fabricated assembly batch. This rule could only be broken with the permission of the company's director.

The use of a metric based on tonnages produced encouraged managers to focus on maximum utilization of capacity. This was true for the design and engineering process, the fabrication process, and even for the transportation process. Simple components were detailed first; heavier components were fabricated and shipped first. However, the construction site could not benefit from this as they received incomplete batches for the assembly process. This maximum utilization strategy led to high levels of work-in-progress (WIP) – open batches from different projects under production, as shown by the inventories in the plant yard (Figure 4), in terms of number of batches. The level of inventories also shows that some of the complete batches were not ready to ship, because of some bureaucratic reason.

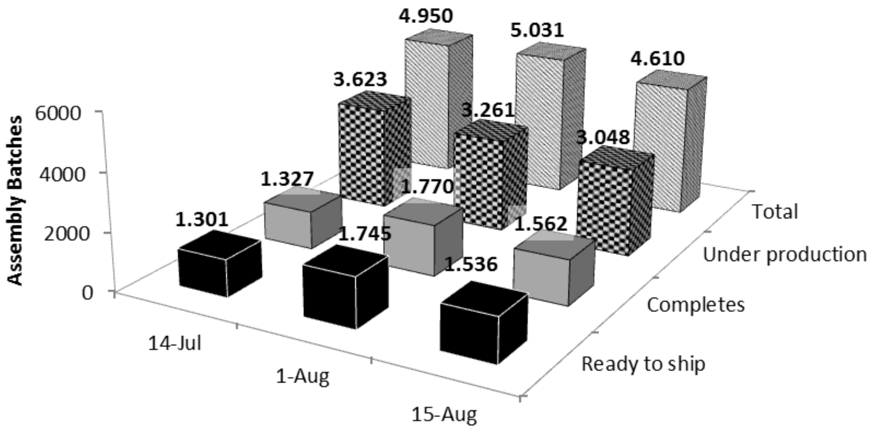

Figure 4. Inventories in the plant yard

IMPLEMENTATION PHASE

The existing scenario revealed the need for a different understanding of the assembly batch. It emerged as a minimum batch for the assembly, as it encompasses the minimum number of column axes to build a section of the building that can be fully assembled. However, this basic rule was still broad, causing difficulties in the fabrication, packaging and shipping processes. An important aspect to manage production and controlling WIP in ETO systems is to understand how to manage nonstandard products. Caron and Fiore (1995) argue that the benefits of the problem of the traditional scheduling techniques can be overcome by using assembly kits for promoting a better logistics flow and controlling the level of WIP in the production units.

The development of the loading plans was the first step for understanding the assembly kits as a way to develop a method to control WIP in ETO prefabricated systems. The initial analysis was made in structural elements which were heavy components with different dimension sizes. This kind of load was hard to organize and were often the least optimized freights. Each load should contain the right amount of components to start the assembly process on site. This means that each assembly batch was divided into a sequence of truckloads. The first of them should containing all the auxiliary pieces from that batch, such as bolts, flanges, etc. The site manager should be able to start assembly without waiting for the second load.

The loading plans worked as an integrative tool, joining three sorts of information: the component dimensions and weight; the assembly sequence; and the shipping constraints. First, each structural component was sequenced according to the assembly requirements. Then, the loading plans were developed using plan views of the components, showing the position of the elements on each layer of the truck. In parallel with the drawings, a spreadsheet was fulfilled showing the key information for the components (name, site axis, size, place in the truck, and weight). Those spreadsheets were important both for the Logistics Department for planning the loads and for the defining the loading plan to ensure that each layer was lighter than the bellow one.

The development of each loading plan required a close interaction between the research team and the logistics team. This was important for creating learning cycles, in which the main decisions and conclusions were tested. The acknowledgement of the product constraints played a key role in planning well-defined batches. Figure 5 summarizes the main decisions taken during the development of the loading plans. It shows the main dimension and weight constraints of the components for the shipping process. This analysis was the first step to standardize the process for developing the loading plans. The singularities of each assembly batch were also identified but these are not discussed in this paper, due to limitations of space.

The loading plans were first implemented for a set of three sites. The site managers from those sites highlighted gains in transparency, which made it easier the identification and control of components, reduction in the demands for transportation equipment. In order to confirm the reported benefits, the company measured the impact of applying the loading plans in one site. In this case, there was a productivity improvement of 20% in the assembly process, comparing to the best productivity reported in historical data.

Although there was a clear positive impact on the assembly phase, the shipment process did not report similar benefits. There was an increase of 50% on the time required for loading a truck. One of the main causes identified for this problem was the fabrication sequence. As described earlier, the plant used to optimize production by focusing on reducing setup times instead of finishing assembly batches. The amount of components resulting from that strategy made it unfeasible for the logistics team to organize the yard by project. Therefore, each load requires components from different parts of the yard, which were difficult to find and demanded long distances of transportation. The amount of components a forklift transports was less than 5% of a truck capacity, which means that it would be necessary, at least, twenty displacements inside the yard to complete one loading.

Dimension		**Weight**	
Constraint	**Justification**	**Constraint**	**Justification**
The longest pieces must stay in the inferior part of the truck	A longer piece over a small could destabilize the loading causing serious safety risks	The weight of each layer must be considered (heavier pieces in the inferior level)	The center of gravity closer to the ground, increasing the charge stability
Avoid cantilever in pieces	A cantilever could cause shear failure	Centralizing weight inside the layer must be considered	The center of gravity close to the center helps prevent tipping
The arrangement of beams and columns must be done before the secondary parts	The secondary parts will be used to clamp the main pieces, which are heavier		
Beams and columns with the same height should be in the same level	Increasing the stability for the superior level decreases the time needed to adapt the wood supports and allows better distribution of the load on the truck		

Figure 5. Constraints for the loading plan development

When the loading was made without a loading plan, the logistics team used to take all the components they could find from the planned assembly batch, as there was no instruction on how to break it into a set of trucks. The problem to find components would only appear in the last load of a batch. Although the shipment was faster in this scenario, it causes different sorts of inefficiencies at the construction site such as difficulty to find the right components, increase on equipment costs, losses of components and, most of all, increase on assembly time.

DISCUSSION

The definition of the minimum number of components to start the assembly together with the site manager, revealed the possibility to reduce the batch size a little more. It is worth noting that it is not easy to define a minimum batch in this kind of production system, since the client needs to receive the complete building. Although it can be delivered in smaller sections, which were the stages of the project, and further detailed into assembly batches, the amount of work to be performed in one day of execution is even smaller than those divisions.

As highlighted by Laufer (1997), this kind of batching can be regarded as the overlapping of successive phases. The same author states that the key to the success of this overlapping process is to define a batch so that the subsequent and interconnected batches do not need to be redone. For this reason, the connection between the amount of work to be performed and the amount of components that fit a truck load is what define the minimum batch in this study. It is a matter of understanding the product and the load of work provided by a truck.

The problems highlighted in the use of the loading plans in the first phase, revealed that the plant scheduling process should incorporate this analysis, in order to avoid the need to spread the components along the yard and re-join them to attend a loading plan. Although each production phase may develop their own metrics based on their production nature, the establishment of a unified batch, adapted to the assembly process, is an important step toward the integration of the phases, WIP control and lead time reduction. If the transfer occurs through different combinations of components, it will cause a different ways to optimize the production that can lead to a negative impact in the overall process. By contrast, a unique batch encourages the synchronization within the production units and the communication between one another.

CONCLUSION

This investigation aimed to discuss the role of loading plans in the control of work in progress for ETO prefabricated building systems. In this phase of the research, it was possible to obtain a better understanding of the batch size, its impacts for the different production phases in this type of production system. It was observed that most of the losses and inventories could be avoided if there was a better coordination between the outputs from fabrication plant and the deliveries made by the logistics department. The following steps of this research project are related to changes in the fabrication sequence in order to attend site needs. This integration between the fabrication and the construction site plays a key role for making WIP control effective. The use of the same loading plans developed for the construction site to control the end of the flow shop is part of this challenge.

Nevertheless, the use of the proposed guidelines for loading plans in one of the company's products revealed some benefits for the assembly process on site, avoided the shipment of inadequate loads for site demands, and enforced the need for producing what is required by the site even if leading to a certain degree of inefficiency in the plant yard.

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SECTION 3 CONTRACT AND COST MANAGEMENT

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A MANDATED LEAN CONSTRUCTION DELIVERY SYSTEM IN A REHAB PROJECT – A CASE STUDY

Kåre Johan Haarr[1] and Frode Drevland [2]

ABSTRACT

By implementing Lean Construction in projects, a client may improve their project delivery in terms of cost, quality and time. Guidelines regarding public procurement in Norway prevent a large public client of freely choosing contractors. In the project studied in this paper the Norwegian government property developer – Statsbygg – is implementing Lean Construction by mandating, in the tender competition, that the prime contractor and the designers use Lean Construction principles and a handful of selected methods – a mandated Lean Construction delivery system.

This paper address the following question: What are the experiences of using this mandated Lean Construction delivery system in the construction phase with a prime contract in a rehab project? The research presented in the paper is based on a case study of the construction phase of a 470 Million NOK (57 million USD) rehab project of a listed university building with (a) in-depth semi-structured interviews of eight professional key figures from the client, designer group and prime contractor and (b) a document study of project documents and experience reports from the project.

The findings show that the project failed Lean project delivery because of (I) the actors absent understanding of Lean Construction principles and ideal, (II) the lack of real collaboration, (III) the production system was not aligned properly between client and contractor and (IV) the building's amount of unforeseen risks.

The research highlights the importance of project actors' understanding the mechanism behind Lean Construction and the foundation of a real collaboration to reap the benefits. Whether or not Lean Construction is suitable for a rehab project is difficult to conclude based on this research. Further research is needed, where the project's actors are more familiar with Lean Construction.

KEYWORDS

Lean Construction, Contract Strategy, Public Client, Lean Project Delivery, Production System Management

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INTRODUCTION

Lean Construction (LC) is a theory-based methodology for construction (Koskela et al. 2002), which has theoretical inspiration from Lean Production and the Toyota Production System (Howell 1999). Projects are temporary production systems (Ballard and Howell 2003) and Lean is a way of designing systems to minimize waste and generate maximum value (Ballard and Howell 2003; Koskela et al. 2002). By implementing LC in projects, clients may improve their project delivery in terms of cost, quality and time.

In the past years, LC has entered the Norwegian construction industry. The Norwegian government property developer – Statsbygg – has started to implement LC in its projects. One of Statsbygg's strategic goals is to form the industry of tomorrow by being an innovator of Norwegian construction industry.

Guidelines regarding public procurement in Norway prevent Statsbygg of freely choosing contractors or designers. It is mandated in public procurement to use tender competition in construction projects over a certain budget threshold. The public client is obligated to choose the contractor or designer who satisfy the requirements and wins according to the award criteria. The idea of public procurement is to utilize public funds and ensure fair competition, while the industry's competitive power is developed.

In the rehab project studied in this paper, Statsbygg implemented LC by mandating, in the tender competition, that the prime contractor and the designers used LC principles and a handful of selected methods – a mandated Lean Construction delivery system.

Rehab projects are characterized by a high degree of risks where the sources of risks are diverse and often impact as clusters (Reyers and Mansfield 2001). A previous study of a rehab project indicated that it is more difficult to apply all aspects of LC, due to the amount of unforeseen challenges and the fact that design is based on a relatively ambiguous production information (Bryde and Schulmeister 2012).

A previous research on this rehab project, concerning use of LC and BIM in the detailed engineering, concluded that the Lean methodology and the ideal was more or less absent in the design phase. This due to insufficient Lean implementation and lack of ownership to the collaboration phase (Bråthen and Moland 2015).

This paper looks at the experiences of using this mandated Lean Construction delivery system in the construction phase with a prime contract in a rehab project. This is done by answering the following research questions:

What does this mandatory Lean Construction delivery system imply?

To what extent has the rehab project achieved Lean project delivery?

Why has the rehab project succeeded or failed to achieve Lean project delivery?

Firstly, we present a theoretical framework of production systems and Lean project delivery. Secondly, we describe the research methodology. Finally, we introduce the case study with findings and discussion of what the delivery system implies, the extent of Lean project delivery and causes of why the delivery system failed.

THEORETICAL FRAMWORK

LEAN PROJECT DELIVERY

The term "project delivery system" is traditionally used for a project's contractual structure, e.g prime contract. The Lean community understand "delivery" in terms of the work process from a building's concept to commissioning (Ballard and Zabelle 2000).

Koskela (2000) introduced the TFV-theory of production, which complements the three views of production: Transformation [T], flow [F] and value [V]. Lean project delivery (LPD) systems are structured, controlled and improved in the pursuit of the TFV-theory (Koskela et al. 2002), illustrated in Figure 1. Traditional project delivery focuses primarily on transforming resources to products, and neglects or forgets flow and value.

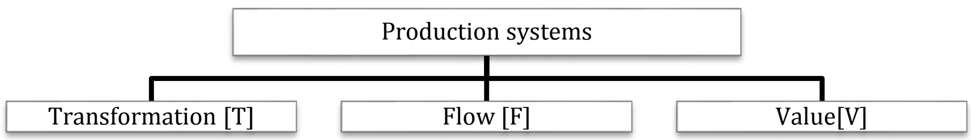

Figure 1: Production systems and TFV-theory.

PRODUCTION SYSTEMS MANAGEMENT

Projects are understood as temporary production systems, which are supplied with materials, information and resources (Ballard and Howell 2003). Production system management – or in other words: Project management – may be divided into three terms: Designing, operating and improving (Koskela 2001), illustrated in Figure 2.

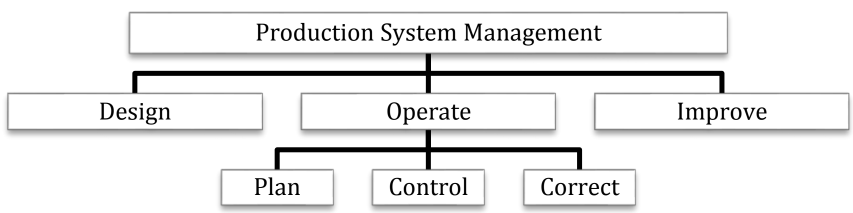

Figure 2: Production system management (Ballard and Howell 2003).

The purpose of production system **design**, also called Work Structuring, is to design the production system that extend from organization to the design of operations (Ballard et al. 2001). Organizational structuring has traditionally been the primary focus, while the design of the production system itself has been ignored, although this is an essential part of the design. Work Structuring serves the production system's three fundamental goals: Deliver the product [T], maximize value [V] and, minimize waste [F] (Koskela 2000). Work Structuring is designed to achieve both the customers' and the producers' purpose. Aligning interests is an important element of the design (Ballard et al. 2001).

Operating is divided into plan (set specific goals for the system), control (advance towards the plan) and correct (change the means used or the goals persued) (Ballard and Howell 2003). **Improvement** is implementing learning, continuous improvement and standardisation in the production system.

All production systems that pursue the TFV goals is a LPD-system (Koskela et al. 2002). However, some will be more Lean than others. **Lean Project Delivery System, LPDS**, (Ballard 2000) is a prescriptive model for project management. The domain in which LPDS is applicable is project-based production systems. LPDS utilizes, among other things, Last Planner System as the control system, Work Structuring to provide reliable workflow, and early contracting and involvement of downstream actors in upstream decisions (Ballard 2000).

PROJECT DELIVERY AS A SYSTEMATIC APPROACH

Project delivery, both traditional and Lean, can be treated as systematic approaches that consist of three elements: Project organization, operating system, and commercial terms and risk management (Thomsen et al. 2009). Table 1 illustrates the different focus for traditional and LPD as a systematic approach.

Table 1: Comparison of traditional and Lean project delivery (Howell et al. 2013)

	Organization	Operating system	Commercial terms
Traditional	Command & Control	Activity centred	Transactions
Lean	Collaborative	Flow centred	Relational

The element **project organization** consists of contract strategy and management of the inter-organizational relationships before and during the project execution (Zimina et al. 2012). An essential part of LPD is to select the right people to set the proper basis for cooperation and include them in the early stages of the project (Howell et al. 2013).

The **operating system** element is to make the project's actors work as one team on a daily basis – The real collaboration. LC tools and methods may be used, but in the end it requires creating a Lean culture through leadership (Zimina et al. 2012).

The element **commercial terms & risk management** concerns contracts, risk and remuneration. LPD contracts are based on collaboration, e.g. IPD (Matthews and Howell 2005), while traditional contracts use transactional contracts. Traditionally the risk is distributed and transferred among the actors – The risk is hidden in the commercial terms. A contractor will not hesitate to shift the risk further down in the supply chain. This risk shifting is an illusion, in the end the client will always suffer the consequences (Zimina et al. 2012). LPD understands the risk and shares it. First, the risk is reduced by the operating system that measures and improves the workflow. Second, the risk is reduced due to the project organization where the actors collaborate to reduce it (Zimina et al. 2012).

RESEARCH METHODOLOGY

The research presented in this paper is based on a single explanatory case study involving the collection of qualitative data by (a) in-depth semi-structured interviews of eight professional key figures from the client, design group and prime contractor and (b) a document study of project documents and experience reports from the project. All the interviews were conducted at the end of the construction phase. The research has primarily focused on the construction phase of the project, due to previous researches on the project's detailed engineering phase (Bråthen and Moland 2015; Kristensen 2016).

FINDINGS AND DISSCUSSION

BACKGROUND FOR THE CASE STUDY

The study looked at a rehab project of a listed 115 years old university building. The building is a part of the Norwegian University of Life Sciences and is located at Campus Ås, 30 km south of Oslo, Norway. The building has three stories with an additional basement and attic. The total gross area is about 8190 m^2. The building's interior, exterior and surrounding outdoor areas are all listed and the Directorate of Cultural Heritage must approve every change in the project. The scope of the rehab project was to preserve the unique building and adjust it to satisfy current general education standards.

The project's revised cost frame was 470 Million NOK, approximately 57 million USD. The detailed engineering was completed in the second quarter of 2014, while the construction work started in the third quarter of 2014 with a planned commissioning in the second quarter of 2015. This was later revised to the second quarter of 2016.

The project was organized as a lump sum prime contract, while the design group had a unit price contract. The prime contractor was contracted after the completion of the detailed engineering. LC culture, principles and methods were new for almost all actors in the project.

THE MANDATED DELIVERY SYSTEM

An overview of Statsbygg's mandated delivery system is presented in Table 2. Statsbygg's purpose of the system was to pursue the TFV goals – A Lean Construction delivery system.

Table 2: An overview of the public client's mandated delivery system.

Initiatives/tools/Methods	Phase(s)
Requirement for Yellow belt in Lean Six Sigma (IASSC u.d)	Announcement of tender
A separate inspection-and-partially-uncover contract	Concurrent with detailed engineering
Collaboration phase with a duration of three month	Three month before construction start
BIM, Building Information Modelling	Construction
Pull planning and production control based on Last Planner System's plan hierarchy (Ballard 2000)	Construction
Takt Time Planning (Porsche Takt)	Construction
ICE, Integrated concurrent engineering (Kunz and Fischer 2009)	Construction

By clearly stating the required LC delivery system in the tender announcement, Statsbygg removed unmotivated candidates that did not desire to use LC. The **requirement** of the **certification of Yellow belt in Lean Six Sigma** for the project managers and foremen was supposed to supported this requirement.

A separate inspection-and-partially-uncover contract was executed concurrent with the detailed engineering phase. The purpose of this contract was to improve the prime contract's design specification and prepare for better workflow in the construction phase. The building's interior design was 3D-scanned to be able to make a more accurate BIM-model. A majority of the informants pointed out that this enabled the designers to produce better specifications for the prime contract. Some also stated that the inspection work ought to have had a bigger scope to identify and reveal even more risks that could have contributed to reduce the amount of unforeseen challenges. The effect of this initiative would have been optimized if the same contractor executed both the contracts. This would have made the prime contractor more familiar with the building and potential challenges.

The intention of **the collaboration phase** was to align the project's actors to establish a real collaboration, a mutual understanding of the risks and uncertainties regarding the building, the prime contract's specifications, work drawings, BIM-model, projects goal, limitations and constraints. Each and all of the informants agreed that such a collaboration phase would have great potential. However, the actual execution of this phase was not in accordance with the plan. All the informants pointed out a lack of clear goals, i.e. what documents was supposed to be produced, and diffuse distribution of responsibility, i.e. who was supposed to manage the phase, were the main reasons for the phase failing.

During the collaboration phase, Statsbygg arranged a three-day LC workshop at Porsche Consulting in Germany to educate the actors in LC. The purpose was to learn and understand the principles of pull planning and Takt Time Planning.

All of the informants agreed on the **BIM-model** being useful for both designers, management and construction workers. In each of the four stories a BIM-kiosk was placed. Both the BIM-model and drawings were available at the BIM-kiosks. To support the BIM-kiosks, project leaders and foremen had access to the BIM-model on their tablet computers. However, according to a few informants, the construction workers did not have full confidence in the BIM-model. This, because the contract stated that the BIM-model was subordinate to both the specifications and the drawings – The specifications was prevailing over the drawings and the drawings over the BIM-model.

The **pull planning and production control based on Last Planner System's plan hierarchy** did not work as intended. The pull planning was executed at the start of the construction phase. The meeting sequence of the production control was *14-10-8-4-1*-weeks before each takt zone. The meetings' agenda were as following: 14 week: Designers prepare and coordinate for the next takt zone, 10 week: Designers conduct interdisciplinary control and complete work drawings, 8 week: Lookahead planning, 4 week: Weekly plans, and 1 week: Final preparation for the takt zone – Ready to start.

A majority of the informants pointed out the main reason for failing the project control was the lack of previous experiences with the lookahead process. The actors did not do the needed preparation before meetings, and this made it hard to maintain a sufficient workable backlog. Another important factor was the amount of unforeseen challenges due to not knowing the actual state of the old building – It was difficult to make the required preparations.

The Takt Time Planning, as the pull planning, did not work properly. Again, the lack of previous experiences made it difficult to carry out. To compensate for this lack of experience a consultant was hired to establish the Takt Time plans. Despite this effort, the Takt Time Planning was discarded after a few months. The majority of the informants pointed out that the design of the Takt zones and sequences were not suited for the building's design. The building had vertical shafts, which were to be used for risers for electrical and mechanical installations, while the sequences was in horizontal order. A few informants also stated that there were not enough buffers in the plan to compensate for all the uncertainties present as a result of the insufficient workable backlog. When the Takt-train got off track the train was restarted with driving an empty train through the building, however it derailed soon again.

Integrated Concurrent Engineering (ICE) was a useful and suitable method for the project. It made it easier for the actors to communicate, coordinate and ask for assistance. At the start of the design and engineering phase, all of the designers were present at the construction site four days a week, followed by two days a week in the construction phase and once a week towards the end.

THE EXTENT OF LEAN PROJECT DELIVERY

Each and all of the informants stated that the project's construction phase was more or less carried out in accordance with traditional project management. The project started with the mandated LC delivery system, however after a while, the system was discarded and adjusted for the benefit of more well-known traditional project management.

Some blamed the mandated delivery system for making the project execution more complexed than necessary, while others stated that it contributed to reduce the negative result.

As for the project delivery in terms of cost, quality and time, the project performance was not satisfactory compared to the original cost and time goals, while the quality of the work done did satisfy the client.

CAUSES OF FAILURE TO ACHIEVE LEAN PROJECT DELIVERY

Project organization

The prime contractor was included in the project after the detailed engineering and the separate inspection-and-uncover contract was completed. A significant difference between Lean and traditional project management is the relationship between phases and the participants in each phase (Koskela et al. 2002). A Lean approach is to include downstream actors in upstream decisions. I.e. to include the contractor in the design – not after the design is completed. Furthermore, the initiative to extract the inspection-and-uncover from the prime contract is contradictory to a Lean approach, as it results in a more fragmented organization.

The prime contract's award criteria were distributed 65% on cost and 35% on expertise. In a Lean approach, the expertise criteria ought to be more valued. There was a discussion of adding "experience with LC" as an award criterion, however this was discarded due to concern that the field of competitors would become too narrow.

The delivery system was designed before the prime contractor was contracted. There ought to have been a redesign of the production system to align the interests of the client and the contractor, and to adjust it to the mandated delivery system. After all, it is the producer who must design, control and improve the production system (Ballard et al. 2001)

Throughout the project, the replacement rate of key project management personal was high. This made the project suffer from discontinuity that induced waste. Some of the informants stated that LC ideas almost disappeared with the change of Statsbygg's project manager, who was responsible for developing the mandated delivery system, after the completion of the detailed engineering. The project did not have any Lean process leader that could facilitate and help the actors when needed after that moment.

Operating system

Questions regarding LC revealed a lack of fundamental understanding of what LC is. As mentioned before, LC was new for many of the actors in the project. The similarity between Six Sigma and LC is debateable (Clegg et al. 2010). Whether the requirement for Yellow belt in Lean Six Sigma has contributed to a better understanding of LC is therefore questionable. A majority of the informants mentioned that they had focus on the mandated Lean methods, with only a vague focus on the underlying principles and ideal. When the focus is primarily on the methods and not the paramount goals, it will generate restriction and not flexibility, as it should (Modig and Åhlström 2012). The Fundamental concepts such as minimizing waste and maximizing value (Koskela 2000) as well as Koskela's eleven LC principles (Koskela 1992) were either forgotten or unknown. There was a lack of aligning LC with the actors.

Another factor that may have affected the LPD was the amount of new LC elements. There were many methods to learn and comprehend at once. A more gradual approach would perhaps be more effective. It is common to start with Last Planner System as a pilot implementation to assure reliable workflow. When this is working the actors realize the power of the Lean idea (Koskela et al. 2002).

The majority of the informants experienced the building itself to be a challenge. There were many unforeseen challenges, e.g. missing a foundation wall, problems with reusing the old vertical shafts and rot in the roof, and the extra work was substantial. To plan and maintain a predictive workflow was difficult for the novice LC project team.

Commercial terms and risk management

A majority of the informants mentioned the project's contract form not to be ideal. The contract form was a prime contract without any contractual incentives, except day penalties for too late completion. The mechanics of a prime contract may cause sub-optimization due to the contractor earning extra money for alteration work. When problems occur, the contractor needs to prove the need for a change and get an acceptance in order to be paid. Such a process generate waste and contribute to less collaboration.

As for the design group, they had a unit price contract. There was a high hour consumption. The BIM-model did not have any requirements or limitations to what detail level to satisfy. A consequence of this was an extraordinary detail level on the BIM-model. Some of the informants pointed out this to be non-value adding. There were similar cases of waste with the production of detail drawings. The design group did as told – If the contractor asked for a detail drawing that they did not need, they produced it anyway.

The main argument for a using prime contract was the need for control due to the building being a cultural monument. However, the majority of the informants stated that a partnering contract would have adjusted this factor and improved the collaboration.

There was a lot of time and cost pressure in the project. This lead to sick-leaves and a stressful workday for the actors. The reason for this, according to informants, was an unrealistic cost and time limit. In the collaboration phase the actors noticed the need for a bigger timeframe, even so the project continued without any changes in the timeframe.

CONCLUSION

The mandated LC delivery system is presented in the previous chapter. However, this delivery system's level of "leanness" is debatable. The project's construction phase was more or less carried out in accordance with traditional project management. From a systematic approach the project organization was based on command and control, due to the lacking of a well-done collaborative phase. The operative system did have some elements of Lean tools, of which BIM and ICE worked out, but the important LC culture and the fundamental understanding of the LC principles and ideal were absent. The commercial terms were based on transactions that transferred risk to the contractor.

The main reasons for the rehab project failing Lean project delivery were:

Project management, both at the client and contractor side, failed to implement a Lean culture based on Lean Construction principles and ideal.

Lack of real collaboration. The contract strategy may have affected this, as well as a poorly implemented collaboration phase.

The production system was not aligned properly between client and contractor.

The building's amount of unforeseen risks – The level of variability was high.

This indicates the importance of project actors' understanding the mechanism behind LC and the foundation of a real collaboration to reap the benefits. Despite the project's LPD failure the empirical data indicates that the project actors support a further use of mandatory LC in the public sector in Norway as a mean to reduced waste and costs. Whether or not LC is suitable for a rehab project is difficult to conclude based on this research. Further research is needed, where the project's actors are more familiar with LC. Additional future research proposed is (I) whether Takt Time Planning is suited for rehab projects – Does the need for a high degree of capacity buffers make it an ineffective method, and (II) does the use of the award criteria "LC experience" in Norway unduly limit the competition?

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EARLY CONTRACTOR INVOLVEMENT IN PUBLIC INFRASTRUCTURE PROJECTS

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ABSTRACT

Advocates of lean construction recommend early contractor involvement (ECI) to further reduce waste. Waste reduction and flow, value generation and sustainability can be improved if some of the companies on a project use lean principles and methods. However, if the contractor is organizationally integrated in the early phases, there is a better chance that the product and process designs are consistent with one another. ECI can ensure better value for money by organizationally integrating contractors` knowledge to early phases of projects. This paper contributes to the knowledge about how to implement ECI in public projects. In addition to a literature study, a document study as well as fourteen semi-structured in-depth interviews with key informants from eleven Norwegian public bridge projects were carried out. The EU public procurement directive represents a challenge for public owners when they consider ECI in their projects. However, the studied bridge projects have used various approaches to implement ECI without violating the EU directive. Thirteen approaches are identified in this study. The conclusion is that there are several approaches to implement ECI in public projects, though the contractors' contribution varies a lot depending on which approaches that are implemented.

KEYWORDS

Lean construction, ECI, Project alliancing, Public procurement, Knowledge integration.

INTRODUCTION

It is widely accepted that contractors have better experience than the owner and the designer when it comes to construction knowledge and experience (Song et al. 2009; Walker and Lloyd-Walker 2012). The traditional project delivery methods with open bidding, unit price contracting and owners' quality control provide transparent checks

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and balances, especially when the award criterion is lowest bid. However, the evolving projects demand alternative (evolving) project delivery methods to ensure appropriate project delivery, contract compliance and quality assurance (Molenaar et al. 2007). When the contractors are more experienced with choosing materials and methods, the traditional project delivery methods should be adjusted to promote early contractor involvement (ECI) in order to eliminate waste (Song and Liang 2011).

Lean is about reducing waste and increasing flow and value generation by optimizing design, supply and assembly with an aim of to improve the whole process and to exceed owners` expectations (Furst 2010; Song and Liang 2011). Construction knowledge and experience is one of the important elements in the lean construction concept (Song et al. 2009). In principle, lean construction requires ECI in the front-end phase of projects (Forbes and Ahmed 2010). Therefore, the contractors should first help the owners to decide in what they want before delivering the project (Ballard 2008).

One of the evolving parts of project delivery methods is ECI (Molenaar et al. 2007). Even if ECI has several advantages, also for the design team(Sødal et al. 2014), it faces many barriers during the implementation (Song et al. 2009). The barriers that hinder ECI are even higher for public owners, since they should treat all tenderers equally, be non-discriminatory and act in a transparent way. Furthermore, public owners should take in to account both price and quality during the early team selection in order to comply with EU public procurement directives (European Parliament 2004; European Parliament 2014; Lahdenperä 2013).

During literature study, the authors of this paper did not find much literature that document what public owners do to implement ECI without violating the EU public procurement directive. This paper addresses this knowledge gap by answering the following research questions:

- How can public owners implement early contractor involvement?
- What do public owners do to implement early contractor involvement?

The first question has been addressed on basis of the literature review, whilst the second one using case studies.

RESEARCH METHOD

An initial literature study concentrated on research databases (Google Scholar, Oria and Emerald), library databases and references in relevant articles was carried out. The objective was to identify relevant research and thereafter describe theoretical background.

The literature study was followed by case studies with an objective of investigating the contemporary phenomenon to answer the second research question. To find appropriate cases to study, 20 key professionals that have several years of work experiences in Norwegian Public Roads Administration (NPRA) were contacted. In addition, NPRA's yearly internal projects reports from 2001 to 2013 were studied. In this way, eleven bridge projects that have used/will use different approaches to involve contractors in the early phase were identified.

These projects are:
1) Lepsøybrua,
2) Straumsbrua,

3) Sykkylvsbrua,
4) Tresfjordbrua,
5) Paradisbrua,
6) Linesøybrua,
7) Gullibrua,
8) E6*E16 Flyplasskryssetbrua,
9) Smålenenebrua,
10) E39 Godsterminalenbrua and
11) Tjønnøybrua

Fourteen semi-structured in-depth interviews on the eleven identified cases were conducted according to the methodological approach described by Yin (2013). All interviewees, except one, are from owner side of the projects. The interviewees were selected from different management levels in the examined projects. The interviews were recorded and transcribed to increase data collection reliability. The research ended by a study of documents retrieved from the informants and from NPRA's internal database.

This study involves some limitations. The cases range from Norwegian bridge projects completed after 2001, as well as some that are in the design phase in the course of the study. The other limitation of the study is that all interviewees, except one, are from the owner side of the projects.

THEORETICAL BACKGROUND

The main objective of the client when involving the contractor in the early phase of project development is to get assistance from the contractor by working together as a team with owner and consultant (Mosey 2009; Rahman and Alhassan 2012; Scheepbouwer and Humphries 2011). In order to benefit fully from the ECI both direct and early involvement of the contractor in the early stage is necessary. Direct involvement facilitate for better cooperation while early involvement facilitate for better contribution (Song et al. 2009). This shows that ECI goes hand in hand with lean construction concept.

The phenomena here denominated ECI is covered by different terms in different countries. In addition, there are various means that can be used to implement it such as; target pricing and integrated project delivery, early supplier involvement and interweaving (Gokhale 2011). Recently, Walker and Lloyd-Walker (2012) came up with a comprehensive definition of ECI. According to them, ECI can take place in the internal phase, the project definition and design phase and in the project execution phase. Literally, ECI can happen in all these 3 phases. They further divide ECI into five different approaches depending on in which phase of the project the contractors are involved. "ECI 1" can take place in the three phases. "ECI 2, 3 and 4" can be applied in the project definition and design phase. "ECI 5" can be applied both in the project definition and design phase and in the project execution phase.

Previously, public owners thought that the EU procurement directive rules out project alliancing. Nowadays, that attitude is under change and project alliances, similar in forms to those delivered in Australia, are being undertaken in Europe (Laan et al. 2011). Moreover, the emergence of competitive dialog has facilitated the use of project alliances in Europe (Walker and Lloyd-Walker 2015).

The Finnish Transport Agency experience is that pure alliancing without price component as a selection criteria and single target outturn cost (TOC) could be the best alternative to implement ECI. However, it might lead to difficulties with the EU public procurement directive. Two alternatives are alliancing based on the most economically advantageous tender with capability and fee percentage as a price component (capability-and-fee competition based target-cost (TC)) and dual TOC, respectively (Lahdenperä 2013; Lahdenperä 2015; Lahdenperä 2016). The procurement procedure of alliancing is significantly different from other procurement procedures. Recently, the procurement procedures process of alliancing in Australia has evolved from single Target Outturn Cost (TOC) basis to dual TOC, as depicted in figure 1. The dual TOC approach resembles the competitive dialog approach in Europe (Walker and Lloyd-Walker 2015).

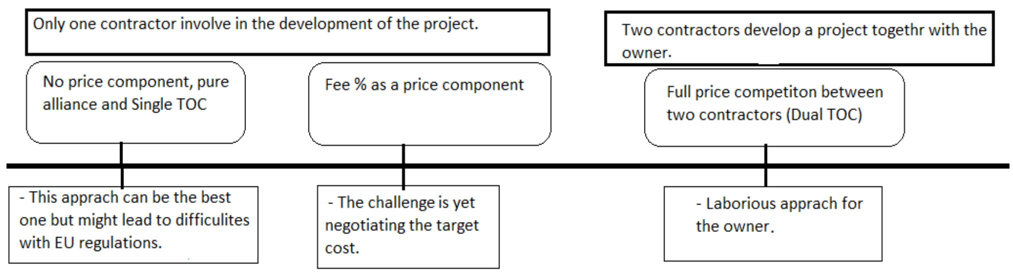

Figure 1. Contractor selection approaches in project alliancing (developed from (Lahdenperä 2013)).

In ECI, the procurement procedure is decisive to achieve integration. The procurement procedure should create a room for creative solutions and for exchange of ideas. Competitive dialogue (CD) and negotiated procedures are the two alternatives owners can use to achieve ECI. By using these procurement procedures, it is possible to use functional specification, conduct a (confidential) dialogue, divide the procurement procedure and perform competition throughout several phases (Lenferink et al. 2012; Van Valkenburg et al. 2008). For simple projects, it is possible to apply negotiated procedure (Lenferink et al. 2012; Lædre 2006; Van Valkenburg et al. 2008), whereas for more complex projects, CD can be suitable. In CD, functional specification and technical requirements, staged process bids and competition over several stages, with most economically advantageous tender can be used to develop a project (Lenferink et al. 2012; Van Valkenburg et al. 2008). To summarize the answers to the first research question, there are several models of ECI. Public owners can choose among these ECI approaches based on their needs through the various contract forms and procurement procedures.

FINDINGS AND DISCUSSIONS

In the following, findings for the eleven first ECI approaches are presented and discussed. The findings are based on the interviewees' perceptions and the document studies. The approaches 1 to 9 have been used in the studied projects to a varying degree. Approach 10 and 11 have not been implemented in the studied projects. Instead, interviewees proposed them as potential approaches for the future use. Due to the limitation in number of pages, not all the approaches are discussed extensively in this paper.

1. Indirect approaches

The interviewees have discussed the use of consultant and in-house construction experience as an approach to integrate the construction knowledge in the front-end of a project. Furthermore, inclusion of contractors in the preparation of handbooks, standards and standardizing of bridge parts are also discussed. It can be realised that, even if this is not a direct project activity, the project benefits from involving contractor knowledge in the early phases.

2. Information meetings

In relation to contractor's involvement, the respondents mention that information meetings with the contractors` branch are used in diverse degrees in the studied projects.

It can be realised that the influence of the information meetings depends significantly on in which phase of the project it is held. If it is held in the early phase of the project, then it is easier for the owner to include inputs form the meeting to the front-end phase of a project. However, if it is held in the later phases of the project, like in projects with a tender conference, it is difficult to implement the inputs in the project. This is because most of the works are already done and the important decisions are already taken.

3. A front-end partnering process

According to the interviewees and documents, the main aim of this process is to create an opportunity for the contractor, the owner and the consultant to get to know each other and to set a common goal. A partnering process will start after the contract signing and ends before the contractors commence construction.

In this approach, it is still possible for the contractor to come up with optimization ideas since the execution phase has not started yet. The success of this approach depends on how much the contractor can be prepared to come up with optimization ideas. Furthermore, it depends on how flexible the owner is to accept new ideas at this stage. This approach should be combined with contracts that accommodate flexibility.

4. Announcing the project with alternative technical solutions

As discussed by interviewees, the Norwegian Public Roads Administration (NPRA) tries from time to time to prepare contract documents that have more than one technical alternative. The aim of the announcement with alternative technical solutions is that the contractor can get the possibility to influence the production method and material selection during the project delivery. The alternatives include all necessary detailed designs and respective procurement documents. The primary motive of NPRA when using this approach is to reach a wider supplier market in order to get several bidders for a project and get the cheapest prices. Consequently, it increases competition.

In order to use this approach, it should be technically possible to use alternative technical solutions without compromising with quality. The limitation of this approach is the contractors options are restricted by the owner`s options and their involvement is not direct and not early enough.

5. Design build contract (DB) or functional description

DB contract based on open procurement procedure was used as an approach to involve contractors from the design phase of a project. In this approach, the contractor gets the responsibility and the flexibility to design the project. The design must be approved after a quality assurance by NPRA. As discussed by the interviewees, even if a DB contract is a suitable approach to implement ECI, the downside is that the owner misses control and the possibility to contribute in the design phase of the project.

While using a DB contract the project should not have very high uncertainty and not be very complex in order to get enough bidders as well as to avoid conflicts afterwards. Therefore, the owner should be able to design the project to an optimal level to minimize the uncertainty and clarify the owner's expectations to the contractors. The findings indicate a lack of integration when DB contracts are combined with open procurement where the owners have less influence on the project.

6. Direct contact with specialist contractors in the front-end phase of projects

The interviewees explained that to implement ECI, the focus should not only be on the main contractors but also on specialist contractors. Specialist contractors have special competence and equipment that both owners and major contractors are dependent on to execute a project. The approach is described as effective since it is based on direct contact with the specialist contractors, and not communicating through main contractors.

It can be perceived that the direct involvement may facilitate for the concepts of lean construction, and thereby reduce waste and add effectiveness to the project. Through that, the project participant may achieve a feeling of partnering and working together.

7. Idea competition

Idea competition is one of the ECI approaches used by public owners in the planning phase of projects. The respondents claim that the dilemma of public owners in using this approach is, whether contractors that participate in the idea competition should be excluded from the bid for construction of the project or not. The cause of the dilemma is to be in line with the EU procurement directive.

It can be seen that the primary disadvantage of this approach is that it lacks continuity and involvement integration throughout the whole project life cycle. In order to decrease the probability of occurrence of the above-described dilemma, proper documentation and well-prepared contract document can be used as protective measures. Furthermore, owners should be proactive to evaluate all ideas identified in the competition before selecting one.

8. Contractors sell their idea to the owner in the early phase

In one of the studied case, one contractor took the initiative to promote the idea to NPRA in the front-end phase. The contractor strongly believed that the company had the appropriate knowledge and equipment to solve the project in an optimal way. Then, NPRA has used the idea after detail designing as an alternative technical solution. It is not common that contractors take such initiatives.

9. Negotiated bidding procedure

NPRA is planning to use a negotiated bidding procedure by combining with turnkey contract in one of the studied project. The reason why the project owner is planning to use this approach is due to lack of internal competence about the subject matter from owner side regarding this specific project. Then, NPRA wants to use the contractors' experience in the front-end phase of the project to get help for the decision process. NPRA's challenge in using this approach is lack of experience with this procedure.

10. Opening for alternative tenders

Opening the project for alternative tender, with other technical solutions than those specified by the owner, has been discussed by the interviewees. With this approach, the contractors can submit one or more alternative solutions to the project. However, this approach is not used in the studied eleven bridge projects.

In most cases, the contractors are not allowed by NPRA to submit alternative tenders because of three major reasons. The first reason is that it is difficult to control the quality of the alternative offers in the short period between bid opening and contract awarding. The other one is that it is difficult to compare bidders based on different competition grounds since lowest price is the most used competition base. The last reason is that bridge projects have quite long-lasting control and approval procedures. If the contractor comes up with alternative offers, it will most probably delay the whole project delivery. The finding illustrates the owner may need to be cautious of this approach as the duration and thereby the cost can be influenced by the variety of alternative tenders.

11. Other approaches

The interviewees proposed competitive dialogue and project partnering as potential approaches for implementing ECI. However, none of these approaches was implemented in the studied projects. In addition, project alliancing was identified as an approach through the literature study.

CONCLUSION

The overall conclusion is there are several approaches to implement ECI in public projects. Twelve of the approaches (1-12) have been identified from the case studies. Approach 13 is identified from literature based on the Finnish Transport Agency`s experience. Table 1 shows the thirteen possible approaches identified by this study, and which of the eleven projects that have applied them. The table implicitly illustrates to what extent each approaches have been/will be implemented in the target projects. The thirteen approaches are numbered after how often they appear in the eleven target projects.

Table 1: Frequency of the ECI approaches (1-13) in the investigated projects (1-11)

Approaches vs Projects	1	2	3	4	5	6	7	8	9	10	11	Total
1.Indirect approaches	X	X	X	X	X	X	X	X	X	X	X	11
2. Information meetings	X			X	X		X	X	X	X	X	8
3. A front-end partnering process	X			X	X	X	X	X	X	X		8
4. Announcing the project with alternative technical solution	X	X	X	X			X		X	X		7
5. Design build contract (DB) or function description					X	X	X	X			X	5
6. Direct contact with specialist contractor in the front-end phase of projects	X			X								2
7. Idea competition				X								1
8. Contractors sell their idea to the owner in the early phase							X					1
9. Negotiated bidding procedure					X							1
10. Opening for alternative tender												0
11.Competative dialogue												0
12.Project partnering												0
13.Project alliancing												0

It does not seem to be many studies that have documented what public owners do to implement ECI without violating EU public procurement directive. This research is an initial study with a purpose to fill this knowledge gap by using cases study approach. Even though this study is based on NPRA's experience from bridge projects, most of the research findings can be useful for the majority of public owners governed by EU public procurement directive. The logic behind to come to this conclusion is, since they have similar operating framework and NPRA`s affirmative experiences throughout implementing the approaches. The findings can also be helpful for project owners that want to know the range of possibilities for ECI. However, the contractors' contribution into the projects varies a lot and depends on which approach that is used.

In the future, experiences from ECI in other project types may need to be collected to reveal new approaches as well as to validate the findings. Furthermore, in future research ECI success factors as well as each of the approaches, which are identified in this study, can be studied in-depth in order to compare them with international experiences. In this way, it will be possible to identify and recommend suitable approaches to implement ECI in future projects. These findings, in combination with future findings, would also be valuable for researchers who want to develop a set of best practice guidelines for ECI.

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THE IMPACT OF THE DECISION-MAKING METHOD IN THE TENDERING PROCEDURE TO SELECT THE PROJECT TEAM

Annett Schöttle[1], and Paz Arroyo[2]

ABSTRACT

Social interaction between the owner and the team starts with the tendering procedure. Many public owners use only cost to select the project team. Cost is easy to define and measure, but does not necessarily result in the best team. Some public owners use multiple factors (e.g. quality, expertise, technical capabilities) to find the best team based on a Multiple-Criteria Decision-Making (MCDM) method like Weighting Rating Calculating (WRC) or Best Value Selection (BVS). However, both methods have many shortcomings when helping owners in differentiating among proposals, such as mixing value and cost. We argue that there is a better way of evaluating proposals. We state that public owner should use Choosing By Advantage (CBA) to select the project team. The method is not used in the tendering procedures yet, but could be beneficial in helping owners discern relative value between proposals. CBA is a system, which uses well-defined vocabulary to ensure clarity in the decision-making process. Previous studies already illustrate that CBA provides benefits in order to differentiate between alternatives, because decisions are documented in a greater detail, with a higher level of transparency, and value and cost is separated. This paper builds on a previous research and presents sensitivity analysis on the data of a public project in San Francisco.

KEYWORDS

Best Value Selection, Choosing By Advantage, Weighting Rating Calculating, selection, tendering procedure, project team.

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INTRODUCTION

The method used to differentiate between bidder in a tendering procedure has a big impact on which team is choose to pursue a project, and these of course has an impact on how the project is delivered and its outcomes. The public tendering differs to the private selection process, as different regulations have to be considered and take into account for developing the procedure. A public tendering requires a fair competition which assesses bidders objectively. Therefore, a clear and well developed method is necessary. Factors for assessment as well as the assessment itself need to be defined and explained upfront, before the tendering starts. Once the tendering is carried out, a meaningful change can easily result in claims against the process. Usually Weighting Rating and Calculating (WRC) or Best Value Selection (BVS) are used to select the project team. WRC and BVS are value based Multiple-Criteria Decision-Making (MCDM) methods, which are described in Belton and Stewart (2002). Compared to WRC and BVS, Choosing by Advantages (CBA) is a MCDM-method which weights the importance of the advantages (IoA) based on relevant differences between the alternatives, rather than weighting factors and attributes separately as WRC and BVS does. Using CBA is a paradigm shift (Suhr 1999). Schöttle et al. (2015) did a first analysis of the three MCDM-methods WRC, BVS, and CBA in the tendering procedure to select the project team. This paper compares the three methods using sensitivity analysis in the constructed case.

RESEARCH METHOD

This research builds on a previous research comparing CBA with WRC and BVS in the tendering procedure (Schöttle et al. 2015). The research questions of this paper are:

- How do WRC, BVS, and CBA affect the selection of the project team?
- Which method would be best for selecting the project team?

Based on the constructed case (Schöttle et al. 2015) further simulation will be done using sensitivity analysis (e.g., Triantaphyllou 2000) as well as extreme cases (e.g., Flyvbjerg 2006) to show the impact of the decision-making method and the input variables on the bidder ranking. The analysis contains the impact of the price and score in order to rank the bidders. This paper does not discuss the topic of implementation of CBA in the tendering procedure. The paper first explains and compares the three methods. Secondly, a briefly overview about the development of the constructed case and the results of the previous study is given. Then different sensitivity analyses are presented and the findings are discussed. Finally, the authors conclude and give a statement to further research.

THEORETICAL OVERVIEW

CBA is a MCDM-method which is based on a well-defined vocabulary. Suhr (1999) defines a factor as an element of a decision, a criterion as a "standard on which a judgement is based on", an attribute as a characteristic of an alternative, and an advantage as the "difference between the attributes of two alternatives." CBA compares advantages between alternatives and assigns scores only to alternatives which present an advantage in a factor. Every advantage is linked to the paramount advantage, which reflects the most important advantage for the decision-maker, which in this case is the owner. The principle of anchoring is the key element to assign scores, and cost and value are studied separately. CBA have been successfully used for choosing designs, systems, and materials in the AEC industry to transparently document collaborative decisions (Grant 2008; Nguyen et al. 2009; Kpamma, et al. 2015). It is easy to understand what attributes or characteristics of the alternatives are more valued by the owner. Besides, the method is influenced by IoA and scale of importance, but the anchoring leads to less subjectivity compared to WRC or BVS. In WRC and BVS results are strongly influenced by factor weight, scoring scale, and score of attribute. Weights represent the importance of a factor for the decision-maker and a score of attribute represents the fulfillment of a factor (Triantaphyllou 2000; Belton and Stewart 2002). Every factor of each alternative is scored although the alternative provides no advantage in the factor. WRC and BVS methods do not postulate anchoring factor weights according to the differences between alternatives' attributes. This unanchored judgement leads to unclear meanings of weights and scores resulting easily in misinterpretation. WRC and BVS differ in the strategy of cost consideration. In WRC cost is a factor and the decision is based on the highest score. BVS decisions are based on the lowest cost per score ratio. Even though the ratio represents cost per score, BVS is often defined as a ratio of bid price per value. We state that this definition is incorrect as value is the way of achieving an objective, which can be very different dependent on the individual.

All three methods assign scores individually to factors or advantages in a factor even when factors can be interdependent. For example, an owner could evaluate factors that are related, such as energy efficiency of the building and expected CO_2 emissions during operation. These two factors are related, but an owner may ask to provide information for both, which in a way might be double counting factors, or over valuing the same attribute for a proposal. None of the 3 methods will prevent this to happen. Therefore, owners should carefully consider which factors will be assessed in the decision, and should avoid highly correlated factors. Figure 1 specifies the process steps of all three methods.

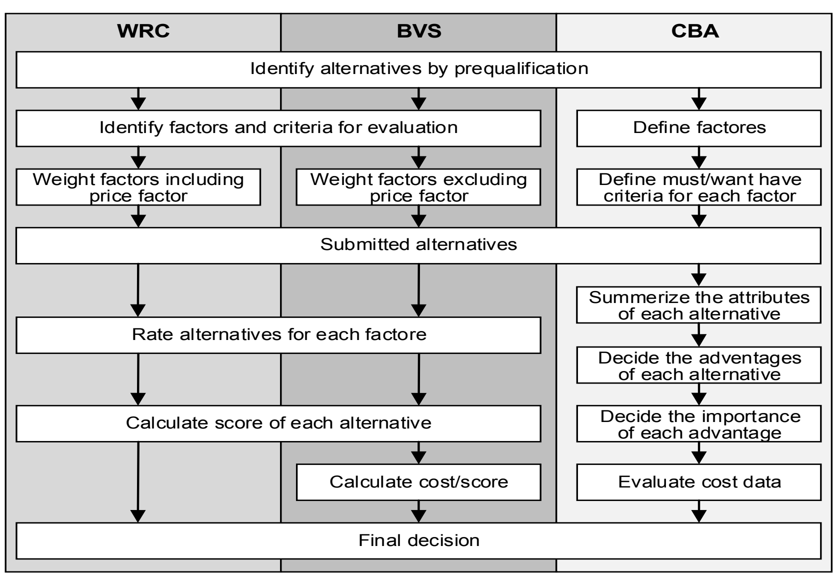

Figure 1: Process steps of WRC, BVS, and CBA

WRC and BVS are easy to implement, because people are used to weight factors and assign scores to attributes. To implement CBA training is necessary. Often the method is implemented wrong. One problem is that some publication applied CBA incorrectly (see Haapasalo et al. 2015 or Rolstadas et al. 2014)[3]. For example, Haapasalo et al. (2015) has many paramount advantages as the authors assigned the highest score (in this case 100) in more than one factor which may lead to confusion, and they state that "factors can be weighted differently based on their importance; however, all the factors are equally weighted in this study", which actually is contrast to the CBA principles where decisions are based on IoA not importance of factors. Furthermore, they scored alternative which provide no advantages. Their example is not transparent as it is not clear how they assigned scores and what the criterions are. Rolstadas et al. (2004) also scores alternatives which provide no IoA. Moreover, both have incorrect sums. The ranking of the alternatives would be different, if CBA would be applied correctly.

CASE BACKGROUND

As stated in the Schöttle et al. (2015) in the tendering procedure an alternative is a proposal, a bidder, or a project team which submitted a proposal. We will use the term bidder synonymously as alternative. The decisions consist in evaluating 3 bidders which are represented as B1, B2, and B3.

The constructed case is based on the tendering procedure of the UCSF academic office building Mission Hall located in San Francisco. To select the project team, every bidder submitted a technical and a price proposal. The technical proposal contains also management skills and knowledge. Both proposals are submitted separately, but to the same deadline. To score objectively, the owner is not allowed to open the price proposal before the technical proposal is scored. The simulation consists of 18 factors clustered in seven categories. The weights (W) of each category are based on the maximal achievable score for each category of the real case. The Development of the scoring scale (0-5) as well as the assignment of the scores is based on the available information where (0) means 'doesn't meet minimum requirement' and (5) means 'exceeds requirements'. As the real case had a stipulated sum, the price proposals were assumed with \$ 93.8M for B1, \$ 92.5M for B2, and \$ 93.7M for B3. In order to compare WRC with BVS, the price factor is weighted 50 % in WRC. Table 1 one shows the scoring of WRC and BVS as well as the scores for IoA in CBA. In CBA the B1 achieved 475 scores, B2 390 scores, and B3 385 scores. The complete CBA table is published in Schöttle et al. (2015).

The bidder ranking of each method is illustrated in figure 2. As shown by Schöttle et al. (2015) for WRC B2 would be selected, who submitted the lowest price proposal and achieved the second best technical score. In the case of BVS and CBA B1 would be selected. B1 achieved the highest score for the technical proposal and submitted the highest price proposal, for BVS that leads to the lowest ration. In CBA the owner (in accordance with law) would also select B1 as B1 achieved significantly the best technical score (B2 achieved 17.89% less then B1 and B3 18.95% less then B1) and compared to B3 the bid price difference is relatively nothing 0.107 % and compared to B2 the bid price difference is relatively very small 1.405 %.

[3] We informed the authors of both publications. Rolstadas et al. (2014) will change it in the next version of the book.

Table 1: Scoring of WRC, BVS, and CBA (Schöttle et al. 2015)

Category	Rating (Scale 0-5)			WRC Calculating				BVS Calculating				CBA IoA		
Technical Factor	B 1	B 2	B 3	W	B 1	B 2	B 3	W	B 1	B 2	B 3	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									100	50	
1.B Workplace	4	3	2									50	30	
1.C Building interior	2	5	3									0	60	40
1.D Daylight	4	2	3									70		30
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											60
2.B Façade	3	4	4										80	80
2.C Building interior: Workplace	4	2	1									60	20	
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									5		40
3.B Vegetated Roof	4	5	3									10	30	
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											30
4.B Materials	2	0	2									20		20
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										40	
5.B Utilities system	2	4	1									10	50	
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									90		60
6.B Site lighting elements	2	4	3										30	10
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™ method	4	1	2									20		5
7.B Set-based design	4	2	2									20		5
7.C Target Value Design	4	1	2									20		5
Price	**2**	**4**	**3**	**0,500**	1	2	1,5							
Overall score					**2,554**	**<u>3,392</u>**	**2,838**		**3,108**	**2,783**	**2,675**	**475**	**390**	**385**
Price [in million $]									**93,8**	**92,5**	**93,7**			
Cost/Quality point [in million $]									**<u>30,177</u>**	**33,324**	**35,028**			

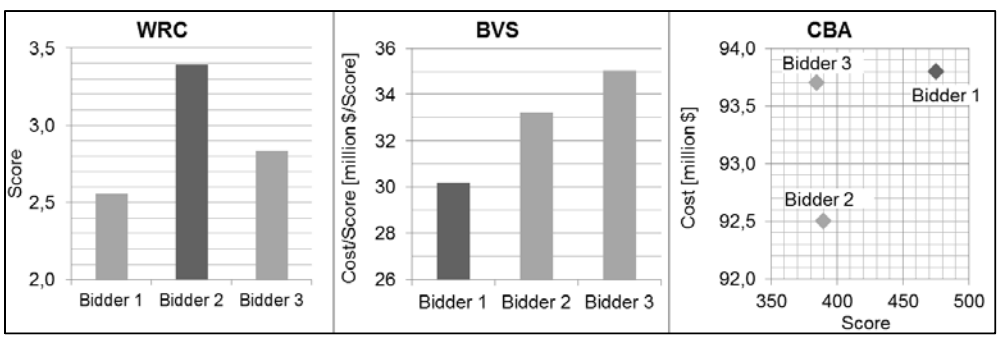

Figure 2: Results (Schöttle et al. 2015)

SENSITIVITY ANALYSIS

The sensitivity analysis was used to show the effects of the methods by changing variables and parameters. The analysis consists of three parts. First the impact of the price factor for WRC was simulated and analyzed. Then the impact of price and overall score for BVS ratio was studied. Moreover, scenarios and extreme cases were constructed to show the impact more clearly. The last simulation shows what happened if equally scored data (category 6) is taken out of the calculation.

IMPACT OF PRICE FOR WRC

By changing the price weight the weight of all other seven categories had to adjust relatively. Figure 3 illustrate the simulation of the price weight for WRC. The lines represent the different bidder submissions as function of the price weight ($y_{B1}(x)$, $y_{B2}(x)$, $y_{B3}(x)$, $y_{B4}(x)$, and $y_{B5}(x)$). It can be seen that as soon as the price factor is weighted 13.98 % B2 will win the bid instead of B1. The weight of the price factor seems small, but has already a high impact on the overall score. With a price weight higher than 30.23 % the proposal with the best performance score will be ranked third place. Table 2 presents the interception of the lines $y_{B1}(x)$ and $y_{B2}(x)$ represented by P_{B1B2} and the interception of the lines $y_{B2}(x)$ and $y_{B3}(x)$ represented by P_{B2B3} as well as the ratio of the performance and price score to the overall score at both interceptions. It is obvious that the closer the technical scores to the price score the greater the weighting has to be to change the ranking and vice versa. Bidder could also submit a proposal which leads to the line $y_{B4}(x)$ or line $y_{B5}(x)$ (see figure 3). B4 shows the extreme case that a bidder could win the bid if the price factor is weighted with 73.57 % when the price proposal achieves the score 5 and the technical proposal achieved 0 scores (see figure 3 P_{B2B4}). Furthermore, the case B5 shows that as soon as the price factor is weighted 50 % a bidder could win the bid with a technical score of 1.783 if the bidder submitted the lowest bid price and achieved 5 scores for the price proposal (see figure 3 P_{B2B5}).

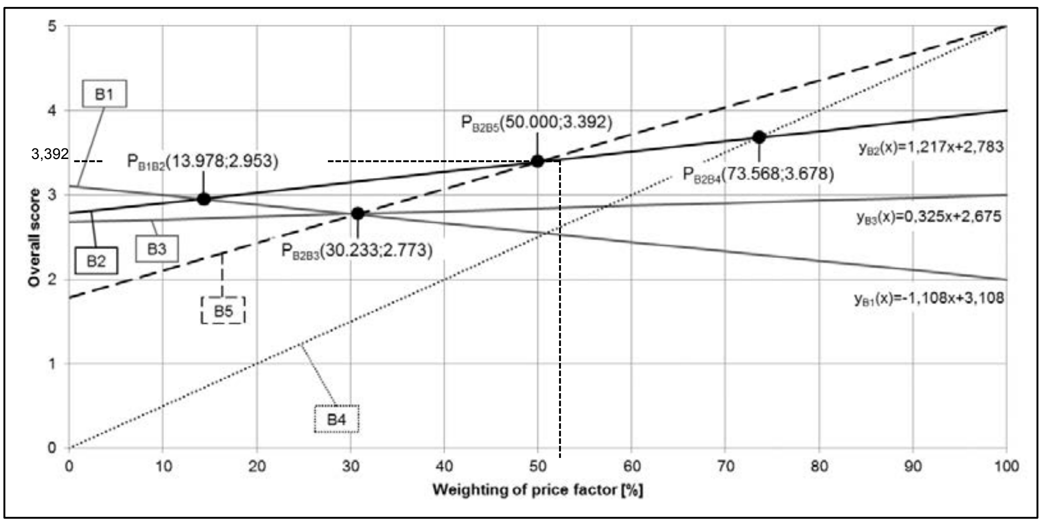

Figure 3: Simulation of the price weight for WRC

Table 2: Interception of the developed lines by simulating the price weight in WRC

	P_{B1B2}			P_{B2B3}		
	B 1	**B 2**	B 3	B 1	**B 2**	**B 3**
Weighted sum of technical score	**2.674**	**2.394**	2.301	2.169	**1.942**	**1.866**
Weighted price score	**0.280**	**0.559**	0.419	0.605	**1.209**	**0.907**
Overall Score	**2.953**	**2.953**	2.720	2.773	**3.151**	**2.773**
Ratio technical score	**0.905**	**0.811**	0.846	0.782	**0.616**	**0.673**
Ratio price score	**0.095**	**0.189**	0.154	0.218	**0.384**	**0.327**

Figure 4 shows what would happen, if the price proposals would be submitted differently and the assigned scores for price change. We show the effects of B1, B2, and B3 scoring 4 ($ 92.5M), 3 ($ 93.7M), and 2 ($ 93.8M). The simulations are represented in the line S4, S3, and S2. Obviously, the lowest bid (score 2) will win as soon as price is weighted 30.23 % (see figure 4). Thus, the price factor impacts the bidder ranking significantly. The higher the price weight the lower the bidders differentiate by the technical factors and the less the ranking differs to lowest bid.

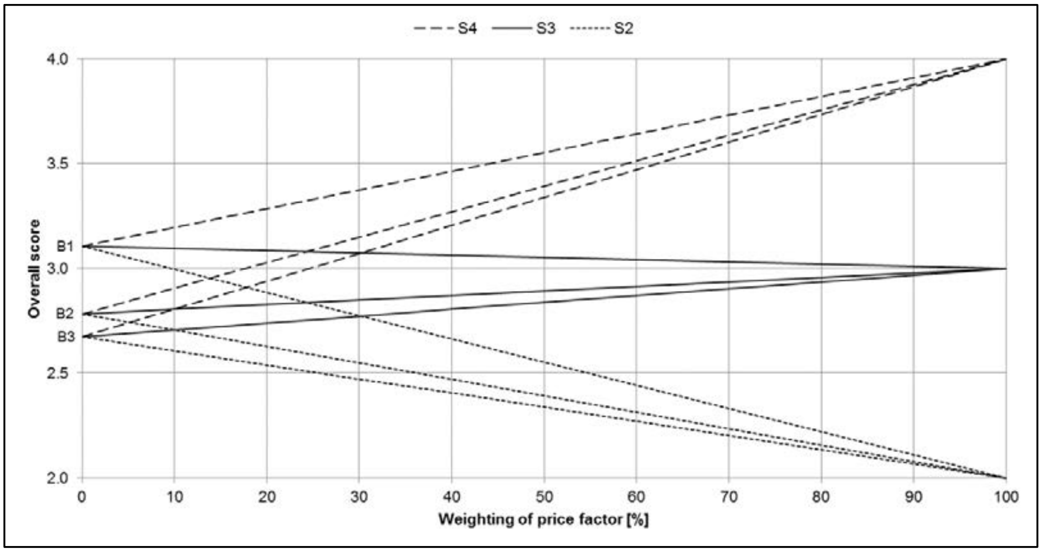

Figure 4: Simulation of scores for price proposal in dependence to the price weight

IMPACT OF PRICE AND OVERALL SCORE FOR BVS

Schöttle et al. (2015) stated that an issue with the BVS ratio could be that "may be an alternative [exists] that has a great cost/score ratio, but the cost may be over budget". The following sensitive analysis will have a look on this subject in detail. Basis of the sensitive analysis is the constructed case with B1, B2, and B3 as shown in figure 5. Now, two scenarios could happen (see figure 5). First, bidder B4 is part of the tendering process and achieved a technical score of 3.2 and submitted a price proposal of $ 96.0M. Compared to all other bidders, B4 submits the highest price proposal, but also achieved the best technical score leading to the best ratio of price per score with 30.000M $\score and therefore wins the bid. Although the price proposal of B4 is $ 2.2M higher than the price proposal of B1 and the technical proposal between B4 and B1 just differ in 0.092 scores the public owner had to select B4. This means that the owner would pay $ 2.2M to get 0.092 more points on the scoring scale. In the second scenario instead of B4 bidder B5 is part of the tendering process and submits a price proposal of $ 90.0M and achieved a technical score of 2.9. In fact, compared to B1 the technical proposal of B5 achieved 0.208 less on the scoring scale, but he difference in the price proposal is $ 5.2M. Even though it could be a better offer for the public owner, B5 will not be selected as the ratio of price per score is higher as the ratio B1 achieved (31.034M $\score > 30.177M $\score). The question here is, is this really value for money? Figure 5 shows clearly the impact of the price proposal for the bidder ranking. As long as another bidder achieves a ratio less than 30.177M $\score B1 would not win the bid. For example, we assume that a bidder achieves the ratio 30.0M $\score and therefore wins the bid. This ratio includes extreme cases. It could happen that a bidder achieves a technical score of 5 and submits a price proposal of \$ 150.0M or a bidder achieved a technical score of 1 and submits a price proposal of \$ 30.0M. The technical scores differ in 4 and the price spread is \$ 120.0M, which amounts a difference of 80 % ($1 \leq x \leq 5$ and \$ 30.0M $\leq x \leq$ \$ 150.0M). In both cases bidders win the bid even though this is anticipated to be less valuable for the owner.

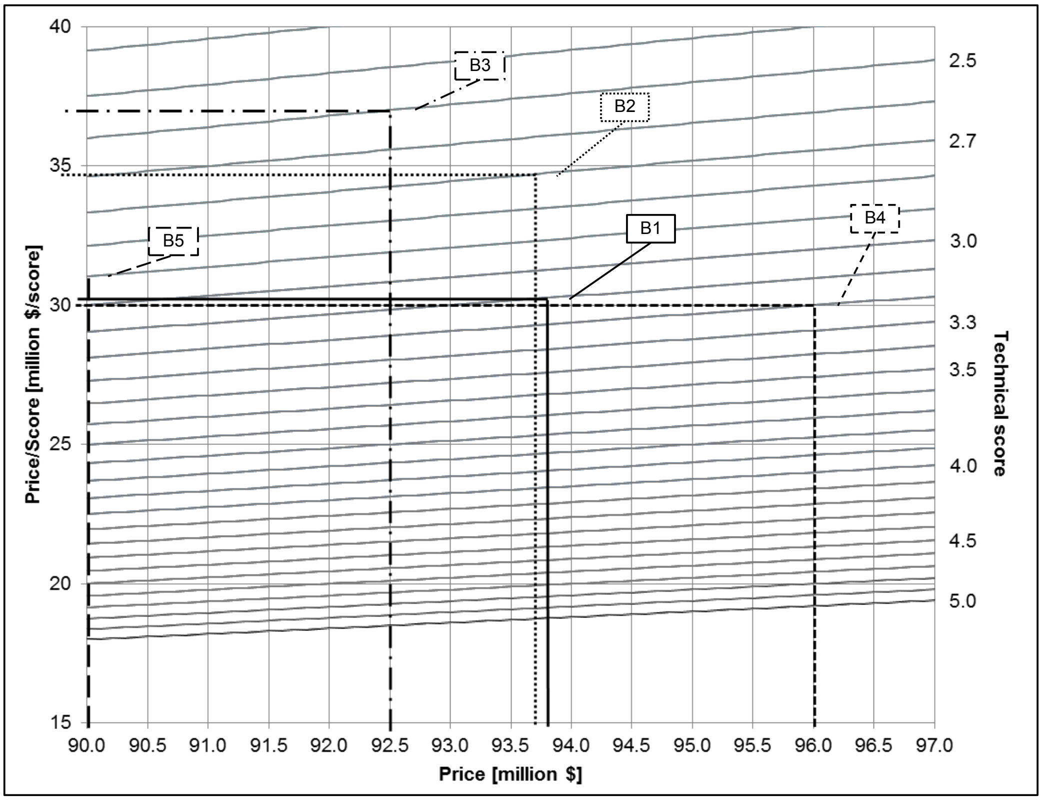

Figure 5: Sensitive analysis for the BVS ratio

IMPACT OF CATEGORY 6 IN WRC AND BVS

For category 6 (C6) "Efficiently Serviced & Maintained" every bidder achieved the same score in WRC and BVS. The following sensitive analysis shows the impact of C6 by changing the weight of C6 and changing all other weights proportionally (excluding the weight of the price factor for WRC). Figure 6 illustrates clearly that in WRC the result will not change if equally scored data is weighted differently as the method is based on linearity. In the case of BVS the simulation shows that the method is inconsistent in the bidder ranking if equally scored data is weighted differently. As highlighted in figure 6 at a point of approximately 88.43 % B2 would win the bid instead of B1 even though only irrelevant data changed. In CBA this situation is different as scores are only assigned to IoA, if no advantage exists in a factor; no score is assigned to any alternative. It can be seen that for C6 every bidder achieved a different score (B1 90, B2 30, B3 70), but as the factors are not weighted, presenting the categories separately does not make sense. Anyways, the alternatives of one factor will never have the same score. Thus, CBA differentiate very clear between alternatives.

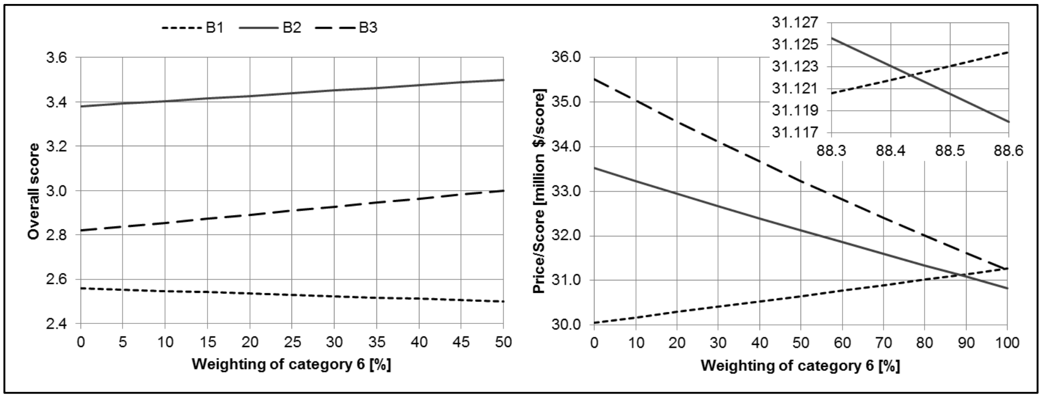

Figure 6: Variation of Category 6

DISCUSSION

The sensitivity analysis of the constructed different cases shows clearly the limitation of the WRC and BVS method. Mixing cost and score can be problematic as it impacts the decision significantly. In WRC a poor technical proposal can still win, if the price proposal is low and the weight of the price factor is with 30.23 % moderately high. It can easily lead to speculative behavior of a bidder trying to win the bid by submitting a low price proposal. As shown in the analysis, in WRC and BVS bidder can still speculate against the tendering procedure in order to win the bid. In both methods the spread between price and technical proposals can be huge, but the overall score in WRC or the BVS ratio can be the same as both methods mix the technical and price score. Hence, cost and score should be studied separately. In the real case the public owner stipulate the bid price, so that the price factor did not impact the bidder ranking. Thus, the owner could define a maximum score which the bidder needs to achieve as well as a maximum accepted price to avoid speculative behavior of bidders. In CBA the problems which are shown in the cases will not happen, as price and technical proposal are studied separately. Even in the case that the price is fixed by the owner; CBA is more beneficial as the way scores are assigned is very transparent and well documented. Scoring 267 factors, like in the real case, with no anchoring makes the scoring irreproducible and not understandable for a third party. Furthermore, decision-making methods should help the decision-maker to ask the right questions in order to make an optimal decision (Arroyo et al. 2014). WRC and BVS do not provide the framework to ask specifically questions compared to CBA tabular method. CBA is based on a specific questions reflected in the criterion to clarify the IoA. In WRC and BVS the meaning of a factor can be very unclear. Bidders can easily misinterpret the meaning of factors and fail in developing a proposal, which offers the best option for the owner.

CONCLUSION

This paper shows the impact of three applied decision-making methods on the bidder ranking and explains why it is beneficial to use CBA in the tendering procedure. CBA is more transparent than WRC and BVS, and does not mix cost with value as WRC or BVS does. However, the implementation of CBA in the public sector still has challenges to overcome. These challenges are related with the widespread practice of publishing factors` weights before receiving the proposals, and therefore owners have to keep them even when factors that are heavily weighted may not differentiate among alternatives. Therefore, further research is necessary to generalize the findings of this analysis and to study how CBA can be implemented in the tendering procedure of the public sector in accordance to the law. Besides, we state that CBA can be improved by overcome the interdependent assignment of scores. Hence, private owners could adopt the method directly.

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PROJECT ALLIANCES AND LEAN CONSTRUCTION PRINCIPLES

Brendan K. Young[1], Ali Hosseini[2], and Ola Lædre[3]

ABSTRACT

There is a trend in the construction industry of adopting more and more relational type contracting methods, for example, project alliancing. In addition to this trend, there is increasing adoption of the lean construction principles. This paper explores the inherent relationship between project alliancing and lean construction in an attempt to highlight the similarities between this project delivery method and the lean methodology.

Based on the literature studied and the performed interviews, this study shows that alliancing does in fact inherently align with some key lean construction principles. Particularly in the area of customer focus, culture and people, waste elimination, and continuous improvement. An understanding of how and where alliancing aligns with lean can lead to a better insight into how the model can be improved. Such knowledge could be useful to practitioners looking at incorporating more efficiencies into the alliancing model by introducing lean concepts

KEYWORDS

Alliancing, Lean Construction, Project Delivery Method, Contract, Value.

INTRODUCTION

Project Alliancing (PA) is a relatively new project delivery method (PDM) that has started becoming popular in recent decades as an alternative to both traditional and other forms of relational contracts. In recent years, alliancing has been receiving worldwide attention with more and more countries exploring its use. Having originated in the UK (Manley 2002), it has become a booming success in Australia. The success in Australia has shown the industry that there are methods to delivering projects alternative to the often-adversarial, traditional project delivery methods.

Lean construction is a project management methodology that has adopted principles of lean that originate from the manufacturing and production industry (Ballard et al. 2007; Howell 1999; Locatelli et al. 2013). Lean construction is considered a philosophy or

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paradigm of managing construction projects and not a stand-alone contractual PDM (Ballard and Howell 2004).

Alves and Tsao (2007), through their study of IGLC papers from 2000 – 2006, identified that there has been a lack of research among the IGLC community in the area of relational contracting. They suggested that researchers *"strive to understand how to implement relational contracting, measure its outcomes, and explain project results to help provide guidance to owners that are interested in working towards lean project delivery."* (Alves and Tsao 2007, 57). Ten years later, there is still a gap in the literature comparing alliancing and lean construction. This paper addresses this issue by providing insight into the relationship between the alliancing project delivery method and lean project delivery.

As the adoption of both alliancing and lean principles in the construction industry has started becoming more prevalent, knowledge of the lean principles inherent in alliancing could be valuable to practitioners looking at adopting lean project delivery. Many countries, particularly in Europe, have started adopting alliancing. In addition, Finland, who adopted alliancing in 2007, has begun experimenting with adopting lean ideology into their alliance projects (Petäjäniemi and Lahdenperä 2012). A clear understanding of the current similarities between alliancing and lean could help improve this adoption and could potentially lead to the creation of improved project delivery models.

Integrated Project Delivery (IPD) is a method used mostly in the United States of America that has many similarities to alliancing, with one major difference being that IPD incorporates a number of lean construction elements (Lahdenperä 2012; Raisbeck et al. 2010). IPD's use is mostly concentrated in America, yet the principles of lean are more prevalent worldwide. Alliancing is often considered at the top end of collaborative and relational contracting (Ross 2003) and is more widely distributed across the globe (Chen et al. 2012; Ingirige and Sexton 2006). In addition, IPD and Alliancing have often been used for different types of projects (Lahdenperä 2012). The key differences between IPD and alliancing will not be explored further in this paper but can be found in the study by Lahdenperä (2012).

To address the identified research gap, the following research question was formulated:

> Does the alliancing project delivery method inherently align with the principles of lean construction?

By addressing this, the report aims to provide a reference point going forward, for both academics and practitioners, to help understand the inherent relationship between PA and lean construction.

METHOD

The research question was addressed by performing a literature and document study. In addition, results from a series of semi-structured interviews were used. The literature study, following the prescription of Blumberg et al. (2014), was undertaken to develop the theoretical background for both lean construction and PA. This was the primary source of information on lean and was key to gaining insight into lean principles. A combination of both journal articles and conference papers was used to get a broad perspective of the current views of the topics. A document study was performed on a number of key government and industry publications covering PA, for example, The National Alliancing Contracting Guidelines (DoIRD 2015) and Alliancing: A Participant's Guide (Morwood et al. 2008). This was performed in order to pick up the Australian government and industry perspective on alliancing. Thus, the document study allowed us to gain insight into both the theoretical and practical aspects of alliancing.

As part of a larger study on the experience of Australian infrastructure alliances, twenty-seven semi-structured interviews were undertaken face-to-face with key industry professionals in Australia. The interview questions were formulated in line with the research question, which considered if the alliancing project delivery method inherently aligns with the principles of lean construction. The interviews ran over a period of three weeks during March and April 2016. Interviewees were contacted based on their experience with alliances. Respondents were chosen among project managers and contract specialists, mostly from client side (government) as the research was exploring when and why alliances are selected. In addition, a number of respondents from contractors (8), consultants (3), and professors (1) were included to get a full industry perspective on the current state of alliancing.

Using a combination of the literature study and document study gave a theoretical insight into alliancing. This insight made it easier to infer the ways that alliancing aligns with lean principles. With the theoretical background in place, interviews were performed to gain practical insight. The combination of theoretical and practical insight helped to analyse how the elements of PA align with the identified principles of lean construction.

THEORETICAL BACKGROUND

In order to draw conclusions on the similarities and differences between PA and lean construction principles, an exploration of the current theory on each topic has been undertaken.

ALLIANCING

Alliancing has developed out of the need and want to improve on, and overcome, the adversarial nature and negative impacts associated with the more traditional forms of project delivery, namely design-bid-build (DBB) and design and construct (D&C) contracts (Laan et al. 2011; Walker et al. 2015). It often falls under the umbrella of relationship contracting (Henneveld 2006; Walker et al. 2013), however, now in recent years, it is beginning to be placed into its own unique category (Chen et al. 2010; Lahdenperä 2012). Moreover, Sakal (2005) states that "*It's important to note that Project Alliancing is more than just a contract; it's a new approach to conducting business and constructing projects that's a dramatic departure from traditional contracting practices - where trust is in short supply and antagonism runs rampant*" .

Alliancing is a collaboration between the client, service providers and contractors where they share and manage the risks of the project together (Chen et al. 2010). All parties' expectations and commercial arrangements are aligned with the project outcomes and the project is driven by a best-for-project mindset, where all parties either win together, or lose together (Chen et al. 2012; Sakal 2005; Walker et al. 2013). The contract is designed around a non-adversarial legal and commercial framework with all disputes and conflicts resolved from within the alliance (Henneveld 2006). This type of project delivery can lead to improved project outcomes and value for money, in part due to the increased level of integration and cooperation between planners, design teams, contractors and operators (Love et al. 2010).

The current most widely accept definition of alliancing comes from the Department of Finance and Treasury Victoria (Victoria 2010, 9) who describe alliancing as:

"… a method of procuring … [where] All parties are required to work together in good faith, acting with integrity and making best-for-project decisions. Working as an integrated, collaborative team, they make unanimous decisions on all key project delivery issues. Alliance agreements are premised on joint management of risk for project delivery. All parties jointly manage that risk within the terms of an 'alliance agreement', and share the outcomes of the project".

Some of the key alliance elements noted from the literature and interviews include open book, integrated project team, aligned client and commercial participants objectives, unanimous decision making and incentivised cost reimbursement.

LEAN CONSTRUCTION

The success of lean as a management philosophy in manufacturing has inspired the adoption into other industries, and particularly into the construction industry. An exploration of the established view of lean construction was undertaken to get insight into its principles. Both lean and the development of lean construction are well described in literature [Lean: (Ballard et al. 2001; Diekmann et al. 2004; Krafcik 1988; Liker 2004) and Lean construction: (Howell and Ballard 1998; Howell 1999; Koskela 1992; Picchi 2001)]. Therefore, this will not be covered in the paper.

Lean principles have been adopted into the construction industry from the manufacturing industry. Lean construction is the management of construction using these principles. According to Howell (1999, 4) there are four points that separate lean construction from traditional practice. *"Lean construction:*

has a clear set of objectives for the delivery process,

is aimed at maximizing performance for the customer at the project level,

designs concurrently product and process, and

applies production control throughout the life of the project."

To take it one step further, we look at the definition of lean construction by Diekmann et al. (2004, iii):

"Lean construction is the continuous process of eliminating waste, meeting or exceeding all customer requirements, focusing on the entire value stream and pursuing perfection in the execution of a constructed project".

In addition to the definition, Diekmann et al., (2004) established five main principles of lean that are relevant to the construction industry:

Customer focus

Culture/people

Workplace standardization

Waste elimination

Continuous improvement/built-in quality

We note that the principles of lean construction are not as extensive as the principles of lean. For example, Liker (2004) identifies 14 principles of lean. To summarise, lean construction is based around maximising value for the customer and minimising waste (Ballard and Howell 2003; Howell 1999; Locatelli et al. 2013).

As well as being based on key principles, lean construction benefits from the use of a number of tools that facilitate these principles. Such tools are presented by Salem et al. (2005) and include Last Planner, Visualisation and Daily Huddle Meetings.

Reasons for adopting lean vary but the results speak for themselves. The work by Locatelli et al (2013) has identified shorter delivery time and higher project performance as being the most common benefits of using lean construction. Ballard and Howell (2003, 132) state that *"Even partial implementations have yielded substantial improvements in the value generated for clients, users and producers"*.

FINDINGS AND DISCUSSION

We have chosen to use the five principles identified by Diekmann et al. (2004) to represent the key principles of lean construction. This section will explore the principles of lean and look into what extent project alliancing inherently aligns with each principle. The discussion presents the authors' interpretation of the studied literature and interviews. We begin by comparing lean construction and alliances with traditional practice before focusing on the five main principles of lean relevant to the construction industry.

LEAN CONSTRUCTION AND ALLIANCES COMPARED WITH TRADITIONAL PRACTICE

By looking at each of the four points identified by Howell (1999, 4) that separate lean construction from traditional practice, we can see that alliancing aligns closely with lean construction.

Alliancing *has a clear set of objectives for the delivery process*, all of which are well documented in the alliance agreement. They are also regularly communicated to the team through various mechanisms that maintain the single alliance culture. At the project level, alliances *aim to maximise the performance for the customer*. They do this by developing a number of Key Result Areas identified by the client and incentivising them to drive performance. The commercial arrangement also drives this behaviour. All parties are aligned; what is best for project is also best for all parties. Thus, when a non-owner participant (NOP) works to maximise their outcome, this in turn should maximise the outcome for the client. A key aspect of alliances is the integrated team from the very beginning of the project. This allows alliances to *design both product and process concurrently*. Identified by many of the interview participants, as being a key benefit of alliances, is that normally sequential processes can run in parallel. The last point is where the comparison deviates. Alliancing has not been known to *apply production control* to the extent outlined in lean construction.

Lean construction is stated as being practical and beneficial to projects that are quick, uncertain and complex (Howell and Ballard 1998). One of the key findings from the Australian interviews was that the top three reasons why alliances are chosen as the project delivery method are that the project had 1. a tight timeframe and/or need for an early start, 2. had high uncertainty, and/or 3. was very complex in nature. We believe that this is an important finding because it verifies that PA and lean construction are two approaches to addressing the problems associated with quick, uncertain and complex projects.

CUSTOMER FOCUS

Alliancing, by nature, is a very customer-centric model. The inclusion of the client in the integrated team ensures that the client is imbedded in the team for the duration of the contract. This allows the client to maintain a large amount of control throughout the entire process. Combined with the open book approach, this also gives the opportunity for the Non-Owner Participants to develop a greater understanding of the customer, what they want, need and value as well as their motives, policies, constraints etc. On the other hand, the client gains valuable insights into the way consultants and contractors operate. This goes a long way to helping the alliance satisfy the customer.

Alliances aligns with this principle of lean as alliances are largely driven by value-for-money. Based on the findings from the interviews, most clients are aware that alliances can be expensive to establish, but choose them for certain projects as they often deliver better value for money than traditional contracts. Clients "pay" for it in that they must be able to commit high-level resources and senior people to achieve the best outcome and value. The Client/customer defines what they value and applies incentivised Key Results Areas (KRA) to drive behaviours to achieve the identified areas of value. Given the track record of most alliances, alliances deliver quality results the first time. They often reduce or eliminate re-work. A large part of this is due to the fact that the client is imbedded in the team.

CULTURE/PEOPLE

Alliances have particular team and personal selection processes. People are selected for roles within the alliance on a best for project basis. People are respected for the knowledge and skills that they can contribute to the project, regardless of their parent company. Locatelli et al. (2013) state that team member training is the most important investment when considering lean construction implementation. This aligns quite well with the results from the Australian interviews where the most mentioned key success factor for PAs is the team. Hence why most PAs follow strict team member selection processes.

During the start-up of the alliance a lot of work is put into developing a single alliance team culture. Alliance workshops and team building activities are performed on a regular basis and because a large emphasis is placed on team culture these activities are continued throughout the life of the project.

WORKPLACE STANDARDISATION

At this stage, our research has uncovered little evidence of workplace standardisation in alliance projects. It seems that alliancing lacks an established set of processes and procedures that resembles that found in lean construction, for example, the 5S tool (sort, straighten, sweep, standardize and systematize) (Salem et al. 2005).

WASTE ELIMINATION

For all the types of waste identified in lean construction (Hines and Taylor 2000), we believe that PA can minimise or eliminate waiting, defects and inappropriate processing. We also believe it can reduce waste caused by variation and the disengagement of people.

Waiting is addressed by the concurrent engineering processes inherent in PAs. Defects and extra processing are often reduced due to the higher quality and performance associated with alliance projects. Variations are minimised or eliminated due to the fact that all parties, including the client, are all part of the one team and any issues that arise are dealt with right away. The results of the interview series in Australia identified that alliances address the disengagement of people. The majority of people interview favoured working on an alliancing project over any other form of contract. Provided the right people are selected to work on the alliance team moral and engagement is kept at a high. Expanding on the previous point, waste is eliminated as the right people are often being used for the right positions, regardless of parent company. This ensures efficient use of resources and eliminates doubling up of resources.

Ballard and Howell (2003,128) estimate that *"as high as 50% of design time is spent on needless (negative) iteration"*. Although no comparable statistic has been found for Alliancing, it would appear that it would be considerably lower when it comes to alliances. Alliances have everybody together, and in the same room, from day one. This means that all parties have an input into the design process. The client can immediately eliminate designs that do not comply with their wishes. In addition, the contractor can identify when designs are not practical and highlight where efficiencies in scheduling, construction methods, material etc. This immediate feedback means that needless designs are not progressed and design rework is minimised.

CONTINUOUS IMPROVEMENT AND THE STRIVE FOR PERFECTION

Alliances encourage open dialogue between all members and decisions are required to be made as best for project. This can lead to moving outside of traditional specifications and requirements associated with traditional contracts. Alliances can accommodate scope change and deal with changes and issues as they arise. In addition, alliances are always challenging the schedule to see how to improve it along the way or to mitigate delays. The commercial and legal framework of alliances facilitates this by removing issues associated with variations. The alliance mindset is to deal with challenges and setbacks as a team.

Alliances have a no blame culture. Lessons learned are distributed throughout the alliance on a regular basis. Everyone is on the same team. Guided by standards but are able to challenge them when necessary. Alliances commit to developing and sustaining an alliance culture that respects the principles of the alliance.

In the view of those interviewed, alliances often deliver "state-of-the-art" results and outcomes as they have a large focus on delivering results. Incentivised cost reimbursement is one way to facilitate this, particularly in non-cost areas as safety, quality, environment etc. All decisions made are best for project. The client can up skill their employees by exposing them to different aspects of the industry by embedding them in the alliance.

CONCLUSION

Based on the literature studied and the performed interviews, this study shows that alliancing does in fact inherently align with some key lean construction principles, particularly in the four areas of customer focus, culture and people, waste elimination, and continuous improvement. The research lacked sufficient evidence of alignment in the fifth area of workplace standardisation. To give a visual representation of the alignment between PA and lean construction we refer to the lean construction triangle in **Error! Reference source not found.**. There is sufficient evidence for PA alignment with the organisation and commercial sides of the triangle. Alliancing aligns with the principle of customer focus, a key element of the commercial side of the triangle. On the organisational side, we have shown the alignment in the areas of culture/people, waste elimination and continuous improvement.

A key difference between PA and lean construction appears in the operating system. Alliancing lacks the workplace standardisation and the use of lean construction tools identified with lean construction. Further research into this area could determine whether alliancing would benefit from directly incorporating the principle of workplace standardisation and/or the lean construction tools.

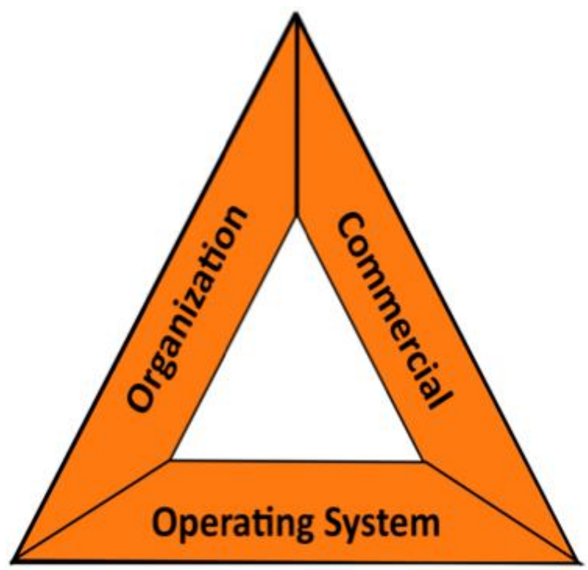

Figure 3: The Lean Construction Triangle (Lean Construction Institute)

An understanding of how and where alliancing aligns with lean construction can lead to a better insight into how the model can be improved. Such knowledge could be useful to practitioners looking at incorporating lean principles and tools into the alliancing model; such is the case in Finland. It could also prove useful to those looking at developing improved collaborative contracting models. This study does not claim that alliancing is a lean project delivery method, but rather that it inherently contains qualities of lean. To sum up; alliancing can be the starting point for an owner interested in the lean project delivery system, as it aligns with many of the lean construction principles.

This paper aims to generate future research and discussion around the relationship between lean construction and alliancing. For example, an in depth look into comparable cases of lean construction and alliance projects could lead to a better understanding of the similarities between the structure, process and performance of both methods. In addition, as the clients continue demanding projects with improved outcomes, higher efficiencies, less cost and less waste, the development on new project delivery methods incorporating lean principles could be an answer.

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TARGET COSTING FOR THE DEVELOPMENT OF OFFICE BUILDINGS

Kron, Christian[1], von der Haar, Rosa[2]

ABSTRACT

In the project development of office buildings, the project budget is set at a very early stage based on both the obtainable market rent as well as the profitability evaluation. The current approach in project development is wasteful and not value-oriented, as the calculation and allocation of the target costs does not follow a standardized process. The estimation of costs for realisation and follow-up costs is corporate-oriented and not carried out detailed enough in the early stages of the project development process.

Although the approach of target costing has prevailed in product development for a long time, so far no implementation in the German construction and real estate sector can be observed. Target costing is necessary to integrate proper cost-planning, cost-management, and cost-controlling in the project development process to create valuable and user-oriented properties.

The objective of this conference paper is to analyse the adoption and potentials for increasing values with target costing pertaining to an optimised cost-benefit-ratio for project development of office buildings. The lessons learned are transferred to an optimised method approach. The focus of this approach for practical application is on the determination and allocation of the component-level target costs in terms of specific requirements of users or project developers. In particular, due to the strict market orientation and focus on customer requirements, target costing provides support for project developers in developing properties of increasing value.

KEYWORDS

Process, product development, target value design, target costing, cost planning

INTRODUCTION

Target costing is a management method originated in Japan which is applied in product development for many years. Target costing should be understood as a strategic approach for cost planning, rather than a simple cost reduction method. The objective of the methodology is generating profit by a market-driven product development meeting the market requirements at market prices. (Ansari et al., 2007)

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This cost management tool is aimed to influence a products cost structure within its development process through an early integration of cost information. The objective is to optimise the cost structure by identifying appropriate cost reduction potential with the focus on meeting customer requirements. (Niemand, 1993) The peculiarity of this methodology is a different perspective of the cost aspect. Instead of considering costs as the outcome of a design, costs are rather deemed as a significant influencing criterion and steering instrument in the development process. (Zimina et al., 2012) Target Value Design was developed as one approach for the adoption of the manufacturing target costing method to the characteristics of the construction and real estate sector. Its processes were applied and improved on projects by an US general contractor and a healthcare service provider. (Zimina et al., 2012)

In Germany the research of target costing for the development of real estate is taking place primarily in scientific studies. Hitherto target costing is not applied in business practices of the construction industry. The documentation of target costing projects occurs mainly in the US. Analysing the project results and the success of the target costing methodology, the focus is mainly on achieved cost savings, whereas related value generation is hardly considered. (Miron et al., 2015) The documented projects in the US are solely developed with the purpose of own use, in contrast to German research on target costing in real estate development, which implies that the development process is operated by a developer.

The application of target costing is significantly influenced by the individual perspective of the project developer. In Germany development projects are mainly carried out by trader-developers with the objective of selling the property after completion to investors. Therefore the development of an optimized approach for the application and adaptation of target costing to real estate development is taken out in the perspective of a trader developer. The focus is set on the development of office buildings, in particular on target cost planning. This paper presents an approach for the adaptation of target costing on real estate development considering potential improvement of existing target costing approaches. The main research efforts were undertaken on the following two aspects:

- determination of a function structure for office buildings
- development of a methodology for estimating drifting costs integrating market and client requirements at an early stage of the development process

RESEARCH METHOD

The initial research contained the concepts and different approaches of manufacturing target costing. In a further step different approaches for the adoption of the target costing method in the construction sector have been analysed. The outcome of this research and actual practices in the real estate sector led to the development of an optimized approach considering the determination of a function structure of an office building and a methodology for the estimation of the drifting costs based on the users requirements. This approach allows an integration of user requirements at an early stage of the development process to obtain value generations through an optimized cost-benefit-ratio.

DEFINING TARGET COSTS AND TARGET COSTING PROCESS

As a first step ahead of the definition of the target costs strategic decisions in terms of product positioning on the market have to be made. The objective is the development of a client-oriented product concept with the specification and the derivation of the target price as the obtainable price on the market. (Seidenschwarz et al., 2002) Thereby the target price represents the client's willingness to pay. The income approach to valuation, a standardised valuation method in Germany, provides a procedure for identifying the market value in terms of the determination of the target price.

The allowable costs are derived from the target price by subtracting the required target profit. (Arnaout, 2001) The allowable costs are defined as maximum costs based on client requirements and competitive conditions (without consideration of existing technology and process standards). (Horváth & Seidenschwarz, 1992)

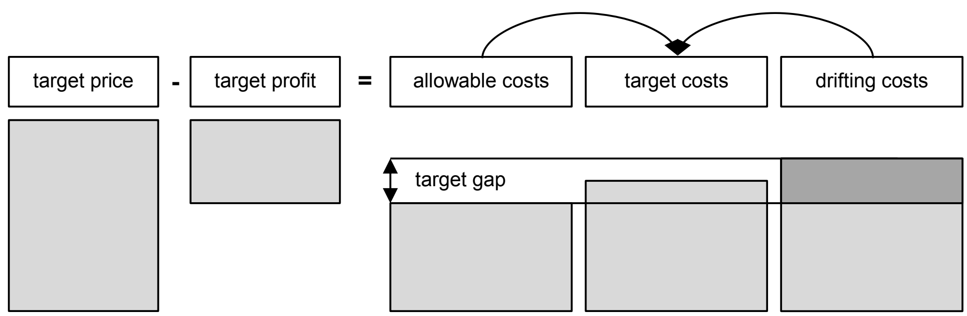

Figure 1: Process of the definition of project-level target costs (Figure 12 in Krupper, 2006)

The allowable costs as a maximum cost limit are set against the drifting costs. The drifting costs are the prognosed standard costs which the company would incure at the current technology and process standard for providing the project. In general drifting costs exceed the allowable costs. The difference represents the target gap and shows the necessary cost reduction target in the development process as the objective of the target costing process. (Horváth et al., 1993)

There is no explicit consistent procedure for the final determination of the target costs for the total project costs. The exceeding difference is deemed to be overcome by means of value analysation and rationalisation efforts. In general the allowable costs do not represent a companies competence and are therefore mostly not obtainable, or at least not in short term. Hence the target costs are established as an amount between standard costs and allowable costs. (Horváth et al., 1993)

DECOMPOSITION OF THE PROJECT-LEVEL TARGET COSTS

The proceedings and presentation of the decomposition of the target costs on a component level are oriented to the approach of the so-called house of quality, a common and essential tool within the quality function deployment (QFD). Quality function deployment is a comprehensive approach translating client requirements in equivalent technical features in every product development and production phase. (Liebchen, 2002)

Figure 2 shows the individual steps of the proceeding of decomposing target costs which are explained in the following in terms of the application in real estate development.

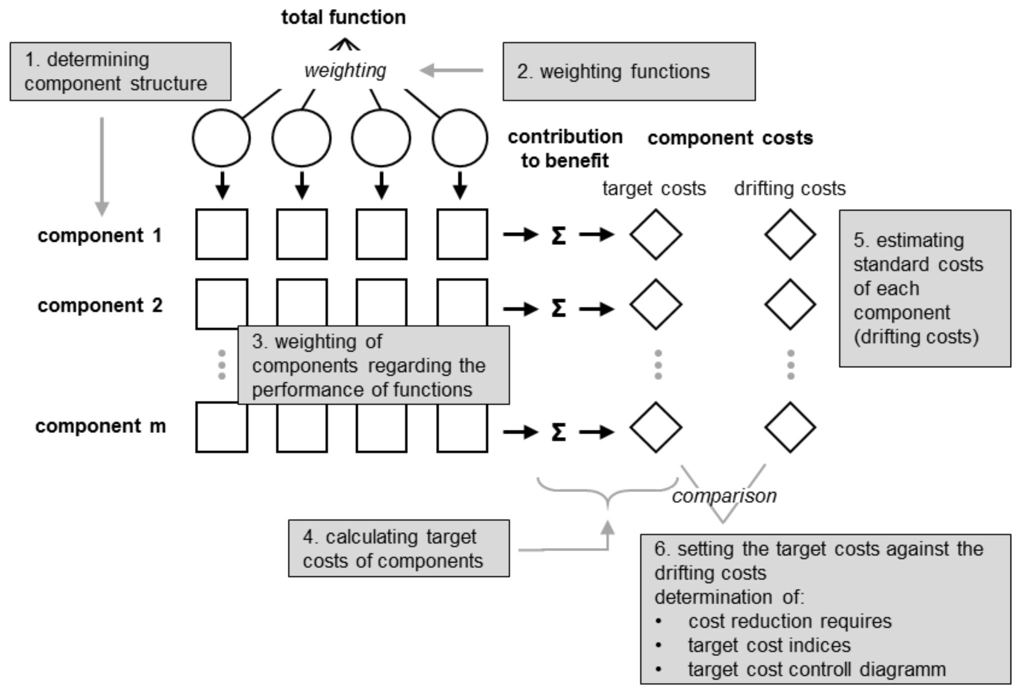

Figure 2: Decomposition of the project-level target costs to component-level target costs using the approach of the quality function deployment (Figure 2-3 in Götze & Fischer, 2008)

Step 1: Developing the component structure

Developing a component-function-matrix requires as a first step the definition of product components. The German Institute for Standardisation provides with the standard DIN 276 a structure for buildings costs which is applicable as a component structure in the target costing process. The component structure can be carried out consistently in the same way by the assumption of building cost groups. The standard DIN 276 forms a framework for building costs, which defines a structure to divide total costs into cost groups. This structured order is maintaining a transparent presentation with the possibility to extend into greater details for a differentiated analysis and constant updates throughout the whole project process. (Greiner et al., 2005) The standard therefore serves as a cost structure and cost planning instrument. (Blecken et al., 2000) The structuring is set by a three level ordinate number. The first level contains following seven cost groups (CG):

- CG 100 – Site
- CG 200 – Clearance and Development
- CG 300 – Structure – Construction works
- CG 400 – Structure – Services
- CG 500 – External works

- CG 600 – Equipment and Work of Arts
- CG 700 – Consultant Fees

This structural system allows the transformation of a planning oriented to an execution oriented cost calculation and leads to the conclusion that the application of the structure seems useful for the target costing method.

Step 2: Definition of the function structure and weighting according to client requirements

The functions of a building are defined and weighted reflecting the client requirements. First, the functions of an office building which describe the client desires and requirements must be determined and weighted according those requirements to be accounted in the further course of the target costing process. There is no common definition of the functions of an office building. There are numerous approaches for valuation methods on the market, but the valuation is based on different criteria. Therefore different valuation approaches for the quality of office buildings are analysed to identify the key function structure. The valuation of these systems is based on criteria catalogues. The relevant criteria for a systematic analysis have been identified and grouped by functions. In addition the function structure of two target costing approaches for real estate development of the German authors Krupper and Liebchen have been analysed. The function structure in Kruppers approach is based on the building quality assessment, a methodology for building valuation. The latter approach is designed to develop residential real estate. The comparison of the valuation systems and methodology approaches results in the following function structure for office properties.

Table 1: structure of functions of office buildings

category	functions
design / appearance	design building envelope
	design office spaces
	design circulation areas
spatial layout	functional structure
	flexibility
access and infrastructure / transportation	access for persons
	safety / security
amenities	sanitary facilities
	social facilities
technical service	information and communication
comfort	acoustic comfort
	visual comfort
	thermal comfort - heating
	cooling / ventilation
	user control

operation	maintenance
	operating costs

Step 3: Identifying the contribution of components for realising the functions

In a first step the percentage contribution of each cost group or component to provide the respective functions must be determined. (Horváth et al., 1993)

Table 2: Determining the proportionate contribution to cost groups for providing the functions

	functions				total
	F1	**F2**	**F …**	**Fn**	
percentage weighting of functions					**Σ = 100 %**
components					
CG 330					
CG 340		**contribution to each component for performing the functions**			
CG …					
CG m					
total	100	100	100	100	

Subsequently the weighting of the component contribution to the realisation of functions is carried out by multiplying the respective function weighting factor (the weighting factor according to the importance of a function to the client from step 2). The total contribution to benefit (on the entire building) of the individual components or cost groups across all functions can be determined by summarising the line total. (Horváth et al., 1993)

Table 3: Identifying the contribution to benefit of each component

	functions				total contribution to benefit of component
	F1	**F2**	**F …**	**Fn**	
percentage weighting of functions					**Σ = 100 %**
components					
CG 330					
CG 340		**contribution to benefit of components**			
CG …					
CG m					**Σ**
total					**100**

Step 4: Determining component-level target costs

In the following step the determined total project target costs are distributed respectively decomposed to the individual components or cost groups to obtain the component-level target costs. The allocation is based on the determined, weighted proportion of benefits of a cost group according to step 3. (Krupper, 2006)

MODIFICATION OF THE ALLOWABLE COSTS – CONSIDERATION OF CONTROLLABLE COSTS

The previous derivation of the target costs is a full-cost approach, taking all cost elements into account. These include all costs for the building construction, including site costs. (Krupper, 2006) In the following step the target costs are divided and broken down into product components. The decomposition of target costs to component-level can basically be proceeded on full-cost basis. However for an effective application of the target costing method an exclusion from target costs of cost elements, which cannot be influenced and controlled by planners is recommended. (Götze & Linke, 2008) For non-controllable cost groups on a planning level, fixed budgets should be set estimated from experience data or contractual arrangements. For this purpose the building cost information center (BKI) offers a database with construction costs information providing cost indexes in Germany (BKI, 2015). The BKI publicises a statistical cost database which is derived from actual costs of numerous completed projects and constantly updated. The subtraction of these estimated budgets for cost elements excluded from the market-oriented design process of the allowable costs results in the modified allowable costs respectively the allowable costs in a narrower sense (allowable costs i.n.s.)

Table 4: modification of allowable costs

target price		Building earning value (without site value CG 100)
- target profit		
= allowable costs	**CG 100 - 700**	
- fixed cost elements	**CG 100**	Site
	CG 200	Clearance and Development
	CG 600	Equipment and Work of Arts
	CG 700	Consultant Fees
= allowable costs i.n.s.	**CG 300** **CG 400** **CG 500**	Structure – Construction works Structure – Services External works

Due to the controllability of costs target costing approach is limited to the investment cost of the building and outdoor facilities.

Step 5: Estimating drifting costs of components

This step involves the estimation of the drifting costs of each component or cost group to be set against the component-level target costs. The respective drifting cost value can be determined based on cost indexes provided by BKI.

Step 6: Comparison of target costs and drifting costs

The final step is considered as the phase of cost controlling within the target costing process. Comparing drifting costs with target costs reveals the cost reduction target and determines the cost reduction target. This step constitutes with the comparison of cost and benefit relation the basis for cost optimisation and fulfillment of client value.

INTEGRATING MARKET AND USER REQUIREMENTS IN THE CALCULATION OF DRIFTING COSTS

Forming the basis for the determination of target costs, drifting costs play an important role within the target value design process. Especially if considering the lessons learned from an example of the application of target costing at a development of a medical office building in the UK which shows the necessity of a more realistic and accurate determination of drifting costs. In this case several unsuccessful attempts of the project had to be reported, as the target costs were first determined too imprecisely, only with a casual square foot estimate. (Ballard, 2006)

An inaccurate and undifferentiated derivation of target costs endangers the successful completion of a project. Since the drifting costs form the basis for decisions about the cost targets, the estimation of drifting costs has to be undertaken with great concern to ensure the accuracy and to develop realistic targets.

A new approach for an accurate and more realistic determination of drifting costs may be the integration of client requirements and needs by means of a weighting of functions. Given that in Germany the construction cost database of BKI is in common use and an essential basis for cost estimations it seems appropriate that an optimised target costing approach refers to their cost indexes. The BKI-database provides cost indexes for categories of simple, average and high standard, whereas for each category a range from lowest to highest and medium value is available additionally. Therefore resulting in a conclusive weighting scale from 1 to 9.

The contribution of a cost group to perform a function whose importance is attached to 1-3 points, the costs are allocated based on the medium value of the simple standard category. For the significance level with 4 to 6 points, the medium values of the average standard category and with 7 to 9 points of the high standard category are measured. The lowest weighting with one point also gives consideration to functions, which are necessary for a building but are from the client's perspective of low value.

Table 5: Using the cost indexes depending on the clients weighting of functions

	weighting points								
weighting points	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
cost indexes according to standard	simple standard	simple standard	simple standard	average standard	average standard	average standard	high standard	high standard	high standard

The calculation of the weighted drifting costs occurs by using the component functions matrix. The contribution of each cost group for performing the respective function ($a_{m,n}$) is determined with the same methodology for the decomposition of target costs according to the QFD.

Table 6: Determining the contribution of cost groups for performing the respective functions by means of calculating the weighted drifting costs.

cost groups (CG)	**functions**				**drifting costs**
	F 1	**F 2**	**…**	**F n**	
CG 330	$a_{CG\ 330,F1}$	$a_{CG\ 330,F2}$	…	$a_{CG\ 330,Fn}$	
CG 340	$a_{CG\ 340,F1}$				
CG …	…				
CG m	$a_{m,F1}$			$a_{m,n}$	
total	**100**	**100**	**100**	**100**	
weighting points (1 to 9)					
standard (simple/average/high)					

The weighted drifting costs are calculated according to the weighting of functions using the respective cost indexes (CI) of each cost group. The costs are determined considering the ratio of contribution for performing the functions and the respective standard.

Thus the weighted drifting costs of a cost group *m* results by their respective contribution to performing the functions in simple standard ($\Sigma a_{m,F\ simple\ s.}$), average standard ($\Sigma a_{m,F\ average.\ s.}$) and high standard ($\Sigma a_{m,F\ high\ s.}$) and the multiplication with the respective cost index ($CI_{simple\ s./average\ s./high\ s.)}$ and the corresponding reference area.

$$\textit{Weighted drifting costs } CG_m = \left(\frac{\Sigma a_{m,\ F\ simple\ s.}}{\Sigma a_{m,n}} \times CI_{simple\ s.} + \frac{\Sigma a_{m,F\ average\ s.}}{\Sigma a_{m,n}} \times CI_{average\ s.} + \frac{\Sigma a_{m,F\ \ high\ s.}}{\Sigma a_{m,n}} \times CI_{high\ \ s.}\right) \times \textit{reference area}$$

The integration of customer requirements in the calculation of weighted drifting costs enables realistic and accurate cost estimation for the desired profile of a building, even in the early stages of a development process.

LIMITAIONS

The distribution of the target costs based solely on the benefits components and the adoption of a proportional relationship between costs and benefits should be considered with appropriate approaches. A possible limitation lies in determining the shares of the cost groups to perform the functions. For this reason future research for target costing in real estate development may involve the following aspects:

- Evaluation of each cost groups contribution for performing the functions
- Integration of ecological factors and follow-up costs, e. g. with the implementation of additional cost groups or operating costs.

CONCLUSIONS

A main weakness and yet essential fundamental basis is constituted in realistic, accurate and reliable planning and determination of the target costs. This part of target costing method is subject of great impact potentials. Therefore this paper contemplates within the framework of determining target costs for office building optimization approaches for the target costing process. The obtained conclusions of this research are stated as follows:

- Target costing is an applicable methodology as a supportive tool for the development of market compliant buildings due to the strict client-orientation.
- To ensure a successful target costing application, realistic and reliable planning and determination of target costs are a core prerequisite.
- Continuous cost information is required in the early stages of the process hence suitable instruments and tools for cost estimation have to be provided.

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ACTIVITY-BASED COSTING FOR PROCESS IMPROVEMENTS

Taehoon Kim[1] and Yong-Woo Kim[2]

ABSTRACT

Current construction industry requires effective process improvement to enhance the productivity and managerial capability. However, construction projects are found to have a limited number of tools for process management on construction sites. Activity-based costing (ABC) technique can provide insightful information on areas for process improvement to minimize waste or non-value-adding activities. However, the ABC has the limitations in reflecting complicated and interactive nature of construction processes. This paper explores how ABC can be practically used for construction process improvement with the support of discrete event simulation (DES) technique. Activity hierarchy is presented as a way to allow sustainable activity cost tracking. The proposed approach can contribute to facilitating easy and practical process control on a basis of more accurate cost information.

KEYWORDS

Activity-based costing, discrete event simulation, process improvement.

INTRODUCTION

Current environments in the construction industry demand effective process management to enhance the productivity and management efficiency. As the construction projects have become more uncertain and complex, the construction industry is suffering from increased waste, poor performances such as overrun and behind-schedule, and adversarial relationships (CMAA 2010). In order to properly respond to such challenges, organizations in the construction industry make continuous efforts to improve their technical and managerial capability among which efforts to improve processes are being made at the process level.

Activity-based costing (ABC) technique can provide very insightful information to an organization regarding areas needing process improvement. The ABC identifies activities in an organization and assigns the cost of each activity resource to all products and services

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according to the actual consumption by resource and activity. Thus, this technique allows the organization to predict the actual costs incurred to perform a work process (Back et al. 2000, Kim et al. 2011). Companies can identify areas for process improvement to minimize waste or non-value-adding activities without relying on speculation and intuition.

However, the ABC has the limitations in establishing more accurate process modelling. In general, construction processes has the complicated, interactive, and dynamic nature. Thus, construction activities may be changeable in their duration, cost, frequency of occurrence, or precedence relationship with other activities (Back et al. 2000). However, the ABC model has the limitations in reflecting those changes without support of a process modelling technique. In especial, discrete event simulation techniques provide a vehicle to overcome the analytical difficulties in complex construction process structures (Back et al. 2000).

The objective of this paper is to explore how ABC can be practically used for construction process improvement with the support of simulation technique. This paper focuses on presenting how to bridge the gap between activity-based costing and process simulation. For this purpose, the use of appropriate activity hierarchy between two systems and strategy for sustainable process improvement are proposed. In addition, a hypothetical case study on pipe installation inspection task was conducted to show the effects of the proposed approach. Through coupling process simulation with activity-based costing, companies can not only better manage process change and develop strategic plans for process improvement, but also predict the performance outcomes in a more accurate way.

ABC IN COSTRUCTION

Activity-based costing (ABC) is a costing model that identifies activities in an organization and assigns the cost of each activity resource to all products and services according to the actual consumption by resource and activity (Cokins, 1996). ABC is found to provide management with a more detailed cost analysis of activities and processes (Kim, 2002).

Unlike resource based costing using a one-stage allocating, which assigns resources to the cost object (i.e. products or services), ABC uses a two-stage costing, traces resources to processes, and then assigns processes to products and services. ABC uses two cost drivers: the resource cost driver (time) and the activity cost driver. Practically, a cost driver is the factor of which the volume is in proportion to the costs of the activity (Horngren et al., 2000). In many cases, the instance of activity is used as the cost driver. In ABC, the volume of the activity cost driver is the only variable to be traced for the period after the resource consumption rate (resource consumption for one transactional activity) is fixed. ABC helps the organization to easily trace the costs of each activity in the process. For the same reason, the organization can use ABC as an accounting tool to keep track of supporting processes that involve overhead resources, which are hardly measured in a traditional accounting system.

Several efforts have been made to apply the ABC in construction domain. Kim and Ballard (2001) explored the relationship between ABC and lean construction and presented an example of applying ABC to construction. In this paper, they presented a cost hierarchy to identify cost drivers in construction. Some researchers and companies (Matteson, 1994, Kim and Ballard 2005, Kim et al. 2011) applied ABC to allocate home office and project overhead costs. Back et al. (2000) and Maxwell et al. (1998) linked process modelling and simulation with ABC. However, they did not allocate activity costs to cost objects. Moreover, their model concentrates on field operations, neglecting activities of overhead resources.

ACTIVITY HIERARCHY

As presented above, compared to ABC, DES can provide more accurate information on resource consumption of each activity by modelling the interdependence of activities. However, if ABC model uses all activities of DES model in allocating activity costs (i.e., ABC uses the same level of activity detail), ABC model will lose its practical value and accuracy in two ways. First, if ABC uses activities at daily-task level with batch-level cost driver such as "the number of inspections", the model loses the accuracy of tracking activity costs in that resource consumption fluctuates each time activity is performed. Second, if ABC uses time-tracking just as DES, the model cannot be sustained due to its maintenance requiring plethora of efforts.

Therefore, the leverage of ABC model coupled with DES as a practical process improvement tool requires appropriate activity hierarchy. The activity hierarchy should be developed to show relations between activities in DES and those in ABC model. This allows for continuous and sustainable activity-cost tracking.

In ABC model, the activity hierarchy affects its cost driver and eventually how its cost would be tracked and calculated. Kim and Ballard's work (2001) differentiates activities based on the intrinsic nature of activities, the costs of which increase or decrease. Similarly, the activities are categorized in (1) functional level, (2) batch level, and (3) daily-task level for this study, as shown in Figure 1. In ABC, you can identify any number of activities with any level of detail. It is challenging to determine the right level of detail; but, in most cases, activities in ABC system are found to be ranged between daily-task level and functional level.

(1) Functional Level: This level includes supporting activities to sustain a project or an organization. Quality control can be activity at a functional level. In many cases, each department in an organization corresponds to each function.

(2) Batch Level: Activities in a batch level, which are related to a group of products or services, are used in ABC. Their cost drivers are directly related to the instance of the activity. The major reason why they are used in ABC is the easiness of updating the volume of cost drivers. Inspection can be an example of activity at a batch level where the number of inspection can be a cost driver.

(3) Daily-task Level: Activity at a batch level can be decomposed into numerous activities at a daily-task level. They are equivalent to activities in most process simulation models. For example, retrieving updated drawing and specification is an example of activities at a daily-task level. Due to fluctuation of resource consumption, the activities at a daily-task level should not use a batch-level cost driver; instead, they use cost drivers at a resource unit level such as time.

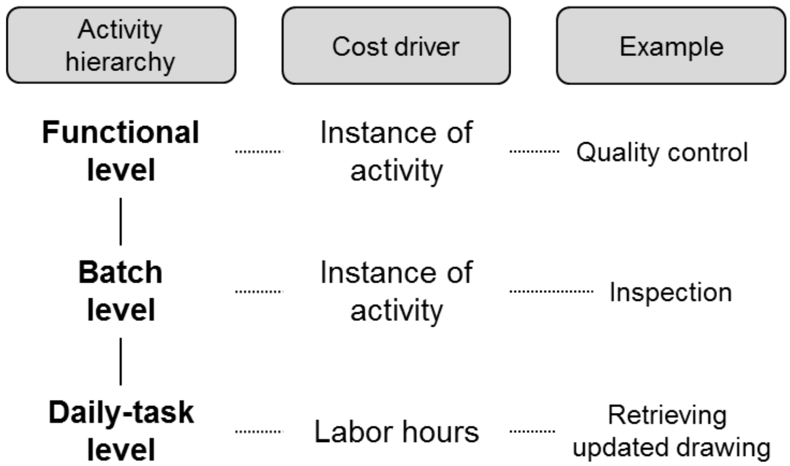

Figure 1: Activity Hierarchy in ABC

The use of activities at a daily-task level in ABC model elicits the problem that the model cannot be sustainable because it is too time-consuming to track durations for detailed activities on a regular basis to update the ABC system. For the same reason, simulation process models are usually developed and run in a planning stage while they are not regularly updated to see if their plan (modeled operation) is operationalized. In other words, the simulation model fails to be used for a control purpose. The key to coupling ABC system with process modeling or process simulation is in the link between activities at a batch level and activities at a daily-task level.

STRATEGY FOR PROCESS IMPROVEMENT WITH ABC (PIABC)

(1) Develop ABC system using activities at a batch level

In order to develop ABC system, an organization's management should first define existing process including process boundaries and individual activities. While this should include all activities necessary to fully specify products and services, most activities are made up at a batch level corresponding to the objective of the system (i.e., process control and improvement). The next step is to identify resources, and cost drivers and their rates of each activity.

(2) Identify activities that need process improvement

Once ABS system is established, the management should seek activities which improvement is required. The comparison with status of other organizations or projects cost helps you identify activities that need process improvement. Suppose the cost driver rate of inspection activity in current project becomes $120 per an instance, while the average rate from other projects showed $80. Then, you will feel a need to enhance the current process for the inspection.

(3) Develop a process simulation model

Next step is to construct the current process model by using a discrete-event simulation (DES) technique. First, you need to decompose the activity at a batch level (i.e. inspection) into sub-activities at a daily-task level, such as retrieve drawing, fill out the inspection request form, transmit the form, on-site inspection, fill out the inspection results, and issue non-conformance report (NCR) (Figure 2). Then, you should identify resource consumption and duration of each sub-activity, and work sequence.

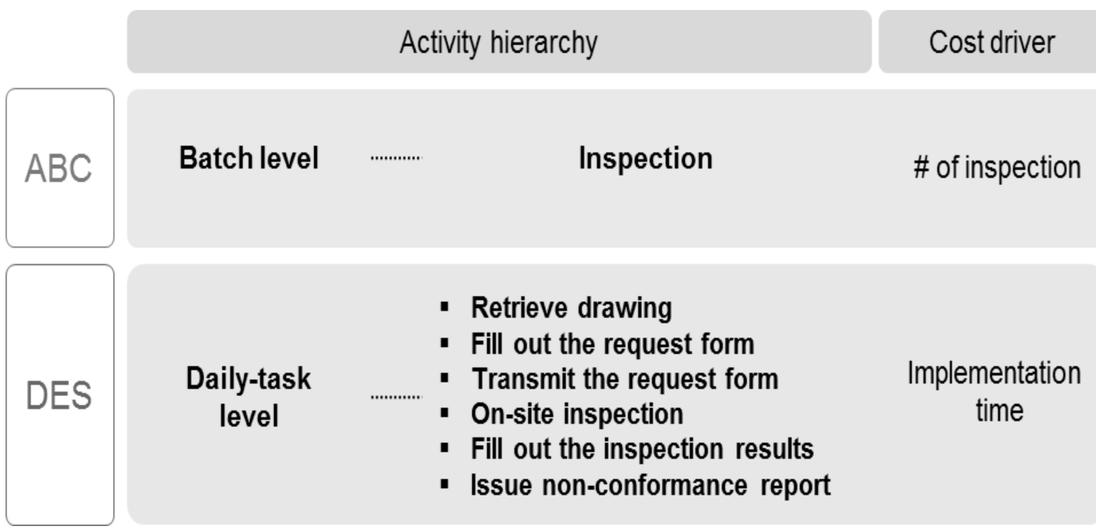

Figure 2: Comparison of Activity Hierarchy and Cost Driver in ABC and DES

(4) Assess the performance and develop the improvement plans

The current performance is assessed in terms of total process time and cost. The performance can be improved through reducing cycle time, cost, errors, and rework or increasing customer and employee satisfaction. Technical, organizational, and/or structural changes are considered. Once an improvement initiative is regarded effectively, you should implement further actions to eliminate process errors and simplify the process.

(5) Update the ABC system and reiterate the processes above.

Once you estimate the total process time and cost through modified DES model, the cost of activity at a batch level (i.e. A NEW COST DRIVER RATE) is determined. You should update the information into the ABC system and track the volume of cost drivers at a batch level.

You should reiterate the processes above as a vehicle of continuous process improvement.

EXAMPLE

Suppose that there is a construction company which conducts sewerage pipe rehabilitation project. The ABC system can consist of many activities in a batch level, such as set up, procurement, pipe installation, and inspection. Among them, a pipe installation inspection can be one of the most frequently occurring tasks, which requires careful management. In ABC system, the activities related to this task can be composed of two cost pools: 1) Inspection (including retrieve information, develop and transmit inspection document, inspect, approve, etc.), 2) NCR (including take picture and issue NCR).

Table 1 and 2 shows the resource consumption rate and activity cost incurred during a week for two activities (i.e. Inspection and NCR). Resource consumption rate represents what percentage of time during a week each resource consumes in two activities. The values can be obtained through interviews with each personnel. Activity cost can be calculated by multiplying the resource consumption rates by weekly wage of resources ($1,625 for GC, PE; $1,800 for GC, QE; $1,475 for SC, PE; $825 for Clerical; $1,550 for INSP, II; $1,450 for INSP, I). As a result, in ABC system, weekly activity cost will be $2,322.25 for inspection and $556.50 for NCR. Furthermore, assuming 12 inspections and 1 NCR happen for a week, the activity cost driver rate will be $194 for inspection and $556 for NCR.

Table 1: Resource Consumption Rate in Pipe Installation Inspection

Activities	Resource consumption rate (%)					
	GC, PE	GC, QE	SC, PE	Clerical	INSP, II	INSP, I
Inspection	20	25	25	8	35	40
NCR	-	5	-	2	15	15

Note: GC(General Contractor), SC(Specialty Contractor), PE(Project Engineer), QC(Quality Engineer), INSP(Inspector), NCR (Non-Conformance Report)

Table 2: Weekly Activity Cost

Activities	Activity cost ($)						Total
	GC, PE	GC, QE	SC, PE	Clerical	INSP, II	INSP, I	
Inspection	325.00	450.00	368.75	66.00	542.50	580.00	2,322.25
NCR		90.00		16.50	232.50	217.50	556.50

If the cost driver rates related to pipe installation inspection task are higher than those in other projects, detailed process modeling should be developed for the process improvement. As the construction-related process are essentially an interrelated network of discrete activities, this study uses a discrete-event simulation technique called cyclic operation network (CYCLONE) (Halpin and Riggs 1992), which is one of the most widely used simulation methods in the construction industry (Hong and Hastak 2007, Luo and Najafi 2007).

The process model for pipe installation inspection was developed based on Kim and Kim (2011) as shown in Fig.3. The model includes both inspection and NCR related activities because inspection activity directly affects the occurrence of NCR. Activity duration can be obtained by actual measurement in the construction site. Rejection of transmitted inspection documents and inspection approval is occurred about 1% and 10%, respectively.

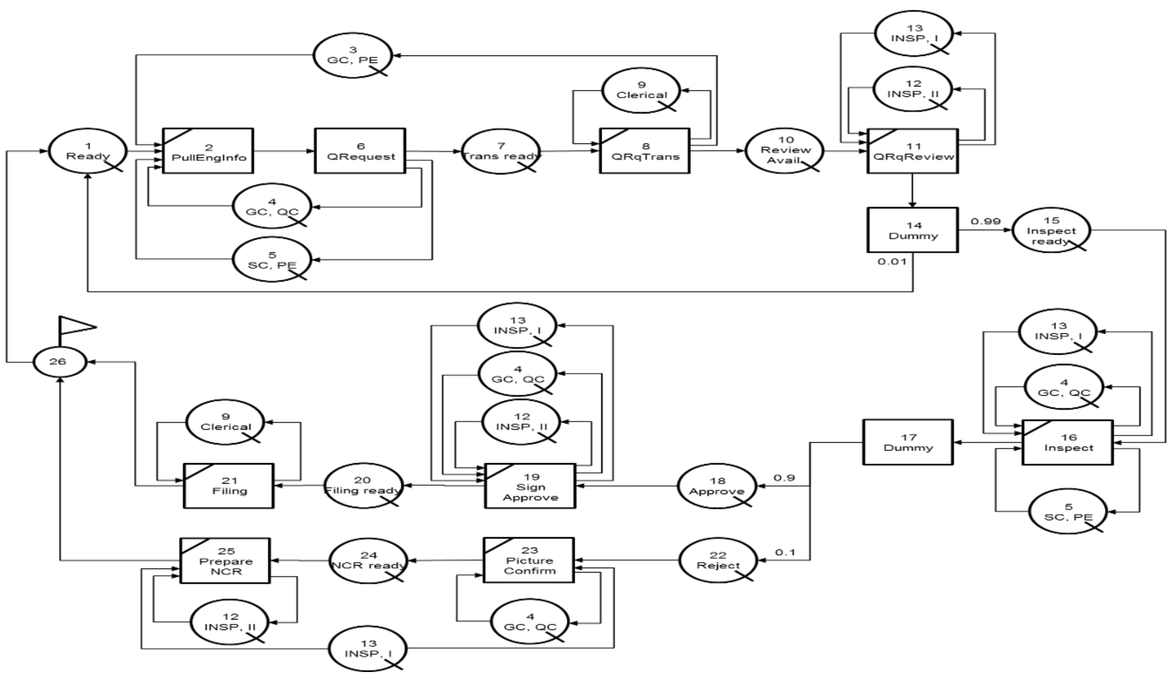

Figure 3: Process Model for Pipe Installation Inspection by using CYCLONE Simulation

Table 3 shows the simulation results for pipe installation inspection process through 1,000 cycles. Average process time and cost per a cycle become 2.95 hours and $170.18, respectively. As a result, in DES model, the activity cost for a week will be $2,042.12 ($170.18×12) under the same assumption (i.e., 12 pipe installation inspections in a week).

Table 3: Simulation Results for Pipe Installation Inspection Process

Category	Values
Total simulation time (h)	2,953.1
Productivity per time unit (cycle/h)	0.3386
Average cycle time (h)	2.95
Cost per cycle ($/cycle)	170.18

In most cases, ABC model uses time-effort % method in which the percentage of each employee's time spent on each activity is tracked. For simplicity and practicality, survey on relevant employees is preferably used. As you can imagine, activity costs using time-effort % method exceed actual usage of resources because time-effort % method does not consider any waste of time such as waiting.

Table 4 shows the comparison result of activity cost for a week estimated from ABC system and DES model. The difference in activity cost would be about $847. It means that actual capability utilization of personnel related to pipe installation inspection task would be about 70% compared to their speculation, assuming that DES model accurately represents the real condition.

Table 4: Comparison Result of Activity Cost

Category	ABC (*a*)	DES (*b*)
Weekly activity cost ($)	2,888.75	2,042.12
Difference ($) (*a-b*)	846.63	
Rate (%) (*b/a*100*)	70.69	

DISCUSSION AND CONCLUSIONS

The example presented in this research shows the following aspects.

(1) ABC model is sustainable in that there is only one cost driver to track on a regular basis (i.e., the number of inspections). PIABC model can be used for control purpose as well by providing the link between activities at a batch level and those at a daily-task level.

(2) The PIABC model has two different activity cost data (i.e., unit activity cost): one from time-effort % method and one from simulation model. The difference is considered to be "unused capacity." Cooper and Kaplan (1992) accounted for the relationship between the costs of resources used and the costs of resources supplied as follows:

Cost of Activity Supplied = Cost of Activity Used + Cost of Unused Capacity

Our approach (PIABC) allows users to estimate their unused capacity by comparing two models. It can be said that PIABC can facilitate the use of more accurate cost driver rate by providing information on used capacity.

In the construction domain, ABC has mainly been applied to allocate home office and project overhead costs. Some researchers tried to link process modelling and simulation with ABC. However, their model used same activities in both ABC and simulation modelling, which seems too time-consuming to track durations for detailed activities on a regular basis. This research focused on presenting how to bridge the gap between the level of activities in ABC and simulation to be an effective tool for construction process control and improvement. For this purpose, activities in ABC should be made up at a batch level, which their cost drivers are directly related to the instance of the activity, while activities in simulation modelling are at a daily-task level. Setting up the right level of detail in activity composition would be the key whether the proposed approach can be practicable and sustainable. The proposed approach can contribute to facilitating simple and practical process control on a basis of accurate cost information.

As seen from the above example, when the two (or more) activities in ABC (i.e., Inspection and NCR) should be included into one simulation process model, simulation result can provide only the total cost (i.e., the cost including both Inspection and NCR). Thus, in order to make the proposed approach more applicable, the researchers are now conducting more tests and case studies on diverse conditions and relations between ABC and process simulation model. We expect to report those in the near future.

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TARGET VALUE DESIGN APPROACH FOR REAL ESTATE DEVELOPMENT

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ABSTRACT

In the delivery of major construction projects, the programming phase is often poorly managed. Additionally, there is often a lack of dialog among the stakeholders during the initial design phase, resulting in projects that are over budget, difficult to construct, and finishing later than desired. Rework, waste, and change orders also often occur.

Target Value Design (TVD) is a management approach that utilizes features of Target Costing and adapts them to the construction industry. TVD's focus is to make the client's value a primary driver of design by improving the project definition during programming thus optimizing the design phase. Despite recent research praising TVD, there still remains a lack of information related to TVD applied to real estate development and construction.

This paper reports on a study aiming to identify weaknesses in processes currently used to define construction projects in light of TVD theory for real estate and construction companies. The authors describe findings from exploratory case studies, various interviews and documents analyzed based on a theoretical framework obtained from a literature review of TVD theory. Consequently, recommendations supporting the application of the fundamental concepts of TVD to real estate projects are presented and discussed, furthering the current debate concerning the adaptation of TVD to the construction industry.

KEYWORDS

Target Value Design, Value, Collaboration, Project Definition, Real Estate Development

INTRODUCTION

Traditionally, managing the cost of a construction project is accomplished in the same manner as managing project duration. Both have been driven by the design of the project and its subsequent implementation, rather than serving as actual criteria for an acceptable design. Cost and time management have attempted to "exert control, after budgets are fixed, by after-the-fact monitoring, detection of negative variances, and taking action to recover to targets" (Ballard, 2006).

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Furthermore, in the delivery of major construction projects, including mega-projects, the programming phase is often poorly executed consequently increasing the probability of project failure. Additionally, there is often a lack of dialog among the stakeholders during the design phase, and some stakeholder's involvement is often too late to be fully effective. Poor programming, lack of communication and late involvement all tend to result in projects that are over budget, difficult to construct and often delayed. This reality happens to a range of project categories including residential, commercial, infrastructure, and healthcare. Consequently, rework, excessive waste, and frequent change orders abound.

Target Value Design (TVD) is a management strategy that is designed to eliminate waste and deliver value by using a 'design-to-cost' method (Kim and Lee, 2010). TVD turns current design practice "upside-down" (Macomber and Barberio, 2007) and can be used to reduce the typical problems mentioned above.

Findings from a literature review of Target Costing (TC) and TVD reveals a critical gap in knowledge. TVD has mainly been studied in a very narrow and specific context - healthcare projects utilizing integrated project delivery methods. Oliva (2014) presented a study relating TVD for housing products in Brazil proposing an integrated method based on levels of collaboration. Oliva (2014) brought valuable contributions to the field and began the current the discussion around adapting TVD to residential projects, but additional research needs occur to anchor TVD fully in real estate development.

Also, applying target costing and TVD in the construction industry is extremely complex, and there is still no formal consensus on this subject. However, there is still plenty of opportunity to explore such approaches for real estate development, which is the main motivation for this research.

The exploratory case studies conducted and reported in this study aim to identify the weaknesses of the project definition processes and the project phases in light of TVD theory for real estate and construction companies. Finally, recommendations supporting integration of the key concepts of TVD into real estate projects are presented.

BACKGROUND

Target Costing (TC), understood as a cost management tool for reducing the overall cost of a product over its entire life cycle with the help of all departments of a company and the active contribution of the supply chain, is becoming a widespread strategic management tool and aims to enhance cost leadership of leading manufacturers worldwide (Kato, 1993).

Some in the construction industry have tried to adapt and integrate concepts from TC. It is possible to understand these initiatives from two different perspectives:

- There are practices that might be labeled target costing or might have similarities in process or organizational structure, such as contract management, cost planning, design-build-own-transfer and partnering projects, target cost contracts (Zimina et al., 2012), but they are not full adaptations;
- There are applications of the original Target Costing concept in the project-based industry for projects that adapt or translate procedures used in manufacturing:

- "Adapted the TC theory" using Lean Construction elements and different collaborative approaches, "creating" Target Value Design.
- Use the "pure theory" from TC from the manufacturing, translating its elements to construction. Such efforts can be observed in Nicolini et al. (2000), Jacomit et al. (2008), Melo (2015) and others.

The original TC concept has its roots in manufacturing, more specifically applied to the new product development phase. The understanding of TC applied in other fields beyond the construction industry is necessary to proceed. On the other hand, TVD is a TC adaptation using lean elements, and so far its literature is limited to this community.

According to Zimina et al. (2012), the introduction of the Target Value Design technique is another attempt to bring and anchor the target costing practice in the construction industry. The main idea of TVD is to make a client's value (specific design criteria, cost, schedule and constructability) a driver of design, thereby reducing waste and satisfying or even exceeding expectations.

Several definitions have been assigned to TVD as a practice intended to keep design and cost aligned while delivering customer value by matching design-to-cost (Lee et al., 2010). This approach makes the client's constraints inform design for the sake of value delivery (Ballard, 2011), to provide for integrated project delivery through the collaborative efforts of different stakeholders (Jung et al., 2012).

TVD has two key distinctive features: "designing to targets" to increase the predictability of project performance; and the opportunity for a cross-disciplinary "validation study" to increase a shared understanding about the basis of value, design, budget, and risk (Lee et al. 2012).

To do so, TVD concepts powerfully add value to the pre-design/project definition stage with the involvement of the key downstream players. The phase immediately preceding design has been called by a variety of names, including design briefing, programming, front end loading, and project definition. It involvews interaction among stakeholders communicating purpose, design concept and constraints (Ballard, 2006). The now well-publicized MacLeamy Curve demonstrates why the early involvement of stakeholders in the project definition is critical. Design decisions made early in the process have the greatest ability to affect cost and functional capabilities.

It now seems optimal to dedicate significantly greater time and effort to the pre-design, or project definition phase with the key downstream players involved in business planning, either directly, which has occurred occasionally, or through validation of the project business plan and feasibility studies (Zimina et al., 2012).

According to Zimina et al. (2012), the discussion on target costing in the construction research community is limited. Performing additional TVD-focused studies is necessary. Additional research will enable a better understanding of TVD's principles creating broader, more useful information. Denerolle (2013) does describe the "17 principles" presented by Ballard (2011) linking them to key concepts of TVD. Some simplifications were made, and a new column has been added to incorporate Macomber and Barberio's (2007) "nine practices" for promoting the situations to deliver the target-value from the design process. Table 1 depicts these findings.

Table 1: TVD Key Concepts Framework. Adapted from Denerolle (2013) based on Ballard (2011) and Macomber et al. (2007)

	Key Concepts		TVD Benchmark practices	9 Practices
Organizing (preparing mechanisms…)	Commercial terms and interests alignment	· Contractual agreement · Incentives, accountability	- Some form of relational contract is used to align the interests of project team members with project objectives.	
	Integrated teams and governance	· Timing of the team partners involvement · Owner's participation · Co-location · Core Group	- The feasibility study produces a detailed budget and schedule aligned with scope and quality requirements. - The customer is an active and permanent member of the project delivery team. - Co-location is strongly advised, at least when teams are newly formed. Co-location need not be permanent; team meetings can be held weekly or more frequently.	- Work in small and diverse groups - Work in a Big Room - Collaboratively plan and re-plan the project
	Joint responsibility, transparency	· Team spirit · Trust building · Open book environment	- A cardinal rule is agreed upon by project team members – cost and schedule targets cannot be exceeded, and only the customer can change target scope, quality, cost or schedule.	- Work in a Big Room - Collaboratively plan and re-plan the project
	Functional interface	· Training, shared understanding · Work structuring		
Defining (ends & constraints)	Business case and Target setting	· Access to owner's business case · Whole life cost · How are the targets set? · Linkage to business case	- With the help of key service providers, the customer develops and evaluates the project business case and decides whether to fund a feasibility study; in part based on the gap between the projects' allowable and market cost. - The business case is based on a forecast of facility life-cycle costs and benefits, preferably derived from an operations model; and includes specification of an allowable cost—what the customer is able and willing to pay to get life cycle benefits. Financing constraints are specified in the business case; limitations on the customer's ability to fund the investment required to obtain life cycle benefits. - All team members understand the business case and stakeholder values. - Targets are set as stretch goals to spur innovation.	- Work in a Big Room - Collaboratively plan and re-plan the project - Engage deeply with the client to establish the target-value
	Stakeholder values	· Definition and measurement of value · Link value directly to design components · Scope Changes	- All team members understand the business case and stakeholder values.	- Engage deeply with the client to establish the target-value - Work in a Big Room - Work in small and diverse groups
	Plan Validation	· Validation study process	- Feasibility is assessed through aligning ends (what's wanted), means (conceptual design), and constraints (cost, time, location, etc.). The project proceeds to	

		• · Level of details	funding only if alignment is achieved, or is judged achievable during the course of the project.	
	• Cross-functional Teams	· Clusters • · Collaboration	• - Target scope and cost are allocated to cross-functional TVD teams, typically by facility system; e.g., structural, mechanical, electrical, exterior, interiors, etc.	- Lead the design effort for learning and innovation. - Collaboratively plan and re-plan the project - Work in small and diverse groups - Work in a Big Room •
	• Design planning and analysis of alternatives	· Pull scheduling · Last Planner System® · Set-based design · Value engineering · Risk & Opportunity • · A3, selection methodology	- The Last Planner® system is used to coordinate the actions of team members. - The cost, schedule and quality implications of design alternatives are discussed by team members (and external stakeholders when appropriate) prior to major investments of design time. •	- Design to a detailed estimate - Collaboratively plan and re-plan the project - Concurrently design the product and the process in design sets - Work in small and diverse groups - Work in a Big Room - Lead the design effort for learning and innovation. •
• Steering (means)	• Cost modeling	· BIM · Cost estimating • · Budget reporting	- The feasibility study produces a detailed budget and schedule aligned with scope and quality requirements. - Cost estimating and budgeting is done continuously through intimate collaboration between members of the project team—'over the shoulder estimating'. - TVD teams update their cost estimates and basis of estimate (scope) frequently. Example from a major hospital project during the period when TVD teams were heavily in design: estimate updates at most every three weeks. • - The project cost estimate is updated frequently to reflect TVD team updates. This could be a plus/minus report with consolidated reports at greater intervals. Often project cost estimates are updated and reviewed in weekly meetings of TVD team coordinators and discipline leads, open to all project team members. •	- Design to a detailed estimate - Collaboratively plan and re-plan the project - Work in small and diverse groups - Work in a Big Room •

Table 2: Case Study

	Company 1	Company 2	Office 1	Office 2
Planning	▪ The author used his network obtained after some years of experience in the industry and contacted the companies and offices. A research summary was provided explaining the objectives and approaches and four companies agreed to participate ▪ A presentation occurred in order to clarify and acquaint the interviewees regarding the topic ▪ Data collection happened in December 2015 for all companies and offices			
Description of the Companies	The real estate development and construction companies are small-medium size from Salvador-Brazil. They are the owner, developer, prime contractor and construction manager, performing all project definition, pre-construction and construction phase, sub-contracting design services. The financing can be through own resources or bank loans. The products are residential units or commercial rooms that are sold or rented		The architectural Offices are medium-large design offices located in Salvador-Brazil. They work in a wide range of areas, such as residential, commercial, hotels, healthcare and special projects. They worked with real estate development frequently, mainly only as designers, working directly with the developers and owners	
Type	Semi-structured interviews		Open interviews	
Interviewees	Technical and developer director	Director	Architect director a Design coordinator	Architect Director
Objectives (Understand how is)	▪ Project definition and feasibility studies are carried out ▪ The target set ▪ Project definition interaction with the budget ▪ Stakeholder involvement		Project phase is carried out ▪ Design process ▪ Interaction with the budget ▪ What are the inputs from other stakeholders	
Interview Parts	▪ New Products/Project, Feasibility Studies, and Market Variables ▪ Target Costing and Budget ▪ Stakeholders (designers, suppliers, sub-contractors, final users)		▪ New Products/Projects, Project Definition, Design Stage ▪ Target Costing and Budget ▪ Stakeholders (other designers, suppliers, subcontractors, final users)	
Documents Collected	Management & quality procedures and guides	Management procedures	Management procedures	
Follow-up	Emails and phones call also were necessary to collect missing or unclear data			

FINDINGS

Based on the interviews and documental analysis, the new project development process and the overall project cycle were examined for Company 1 and 2 focusing on the aspects that are relevant to TVD. Also, the design processes were analysed from the perspective of Offices 1 and 2, highlighting what is important for TVD theory and giving additional knowledge use to examine the companies. The results are presented in Table 3.

Table 3: Companies overall project cycle analysis in light of TVD

Company 1	Company 2

Weaknesses: ▪ Only the architect is involved in the research-sourcing-terrain attainment conversation, and the developer does not have other stakeholders values as input to help him to define the product ▪ The first feasibility study does not involve the other stakeholder in the plan validation ▪ Target cost, budget, and schedule are not shared with the other stakeholders ▪ The pre-construction services are developed with informal or incomplete input from main stakeholders (other designers, suppliers, sub-contractors), without integrated teams and governance ▪ In general, main suppliers only give a generic proposal for their services based on unit quantities. They just think about specific solution to the project when it is in advanced phases ▪ Usually, commercial terms and interests' alignment between the developers and the other stakeholder do not generate collaboration ▪ Joint responsibility, transparency is inappropriate ▪ During the design phase, the process is not collaborative, and cross-functional teams or co-location are not explored ▪ Meetings happen without a pre-established frequency and clash-detection, and compatibility reports are late performed ▪ The final budget is only finished after the conclusion of the executive designs and it can happen during the construction phase ▪ There is no target cost or schedule transmitted to the designers. They only receive scope information ▪ Project constraints are not correctly established ▪ The construction phase is unassociated with the project definition and the product development overlaps with the construction phase. Many solutions, construtability issues and clash are identified only during construction phase ▪ There is no input from the final users	**Strength:** ▪ The division between the development and the construction phases is clear ▪ Important inputs are used in the dynamic feasibility studies from other stakeholders ▪ The project coordination is internally performed within a good timing ▪ Constructibility analysis and solutions are performed before construction, usually during programming ▪ Main suppliers and sub-contractors give more than simple proposals and work with the engineering team to suggest constructability solutions and budget input ▪ The pre-construction services (master planning, budget, etc.) are developed with good input from main stakeholders (other designers, suppliers, sub-contractors) ▪ The final budget is finished before the construction phase **Weaknesses:** ▪ Usually, only the architect is involved in the embryo phase, and the developer does not have other stakeholders formal input. Depending on the complexity of the project, it can change ▪ The first feasibility study does not involve the other stakeholder in the plan validation ▪ Usually, commercial terms and interests' alignment between the developers and the other stakeholder do not generate collaboration ▪ During the design phase, the process is not collaborative, and cross-functional teams or co-location are not explored ▪ There is no input from the final users in their regular real estate projects **Offices 1 and 2** The overall design process was evaluated for the architectural offices and weakness were identified. It helped to understand and evaluate the project cycle from the real estate and construction

METHODOLOGY

The first phase of this work consisted of an extensive literature review that established the foundation and source of evidence for all other stages. After this, real estate development and construction company and architectural design office exploratory case studies were completed as part of the research strategy. The adoption of the case study strategy in this work is due to the main intention of this research being to investigate contemporary procedures and processes related to the new project development and project definition phase within a real-life context. Due the exploratory nature of this study, no quantitative data were used or analyzed in order to prioritise the different elements/concepts.

Interviews and documental analysis are used as sources of evidence for this work and are analyzed using a theoretical framework based on the literature review (Table 1).

These exploratory case studies are designed to illuminate the development project definition process vis-a-vis TVD theory. The goal is to identify weaknesses as well as useful procedures to be utilized. The exploratory case studies also reveal potential scenarios for adaption of TVD key concepts.Recommendations and comments regarding the adaptation of TVD concepts to real estate are presented ahead based on the exploratory case studies and the literature review.

Commercial terms and alignment of interests: This is a critical barrier to the implementation of TVD. TVD is mostly used in projects with an integrated project delivery method. The traditional commercial terms carried out in most real estate developments do not create an attractive scenario for TVD. However, there are ways to align the interests of the project team members with the project objectives. Using financial incentives, the creation of partnerships and other contract methods can generate results regarding collaboration necessary for the TVD approach and is a solution that can be further explored.

Integrated teams and governance: Team integration currently occurs, but usually with some misalignment. The chief problem is in the timing. The participation occurs at different stages, and it should be realigned to promote involvement earlier in the process. Small and diverse groups working in "big rooms" is necessary.

Joint responsibility and transparency is not encouraged due to the adversarial nature of many contract agreements, because of this, there is often a lack of communication and no sense of joint responsibility among stakeholders. The creation of partnership and use of financial incentives may help to improve this shortfall. Moreover, better team integration with earlier involvement of key stakeholders employing small, diverse teams in a "big room" can potentially improve the overall interaction among stakeholders. The developer should also share project objectives, plans, and targets for increased success.

Functional interface: This is strongly related to other systems, such as Quality Management Systems and other lean practices. An alignment promoting TVD and lean training is necessary. Traditionally stakeholders are not trained in lean concepts and TVD is not a diffused approach. Workshops can be planned before and during construction.

Business case and target costing: This is one of the main challenges for the original use of TVD in the residential market. The business case is extremely important in TVD theory. To improve the business process, the developer must engage the main stakeholders during planning. Identifying the project value for the final user, owner, developer and other stakeholders is necessary and can be accomplished via workshops.

Stakeholder values: Incorporate stakeholder values into the project may not be an easy task. Workshops, big room meetings and co-location of personnel are all tools that can be used to improve the perception of value. The developer should be aligned with the architect to bring the main concept to discussion. It can come from different sources, including the company's profile, market studies, competition, project location and of course the final user's needs. The other stakeholders must also participate, not only in understanding the core goals for the project, but also incorporating their own inputs and helping with value engineering. The teams should also be selected by value criteria.

Cross-functional Teams: The project coordination is essential to TVD making it necessary to implement tools to enable collaboration. The ideal team includes representatives of all stakeholders. The timing is a barrier for this formation, since the supplies and the constructor start participating more effectively during the construction phase. The developer must ensure that the engineering team (estimation, coordination, planning) has the capacity and knowledge from previous projects to provide important constructability analysis to the design team. The supplier and sub-contactors also need to be more engaged by the designers and estimator in order to bring more comprehensive contributions, not only simple proposals. Small groups and co-location are important.

Design planning and analysis of alternatives: This is more related to the design itself. Several practices from Macomber and Barberio (2007) apply, such as designing to a detailed estimate, collaboratively planning and re-planning the project, concurrently designing the project and the processes in design sets, working in small and diverse groups and working in a "big room". Deadlines and delivery plans must be coordinated. In addition, it is important to highlight other coordination and clash-detections. Alternative solutions to problems are not commonly analyzed collectively at an early stage and frequently, the analysis is performed during the construction phase, which increases the cost of changes and decreases the capacity to use alternative solutions. Performing constructability and alternative analysis with cross-functional teams employing cost modeling is helpful.

Cost modeling: It is currently consistently poorly performed. Building Information Modelling and other advanced tools are not widely used. There is also a lack of interaction among the estimation and design teams. Estimation must be continually performed and updated. Suppliers and sub-contractors play an important role within a project's budget and need to be engaged and participate more deeply in the pricing and solution recommendations. Continuous estimation and budgeting is paramount.

CONCLUSIONS

According to Melo et al. (2014), prior studies have attempted to adapt the manufacturing target costing process to the project-based nature of the construction industry. However, target costing is not a static approach and requires dynamic adaptations. Thus, TC adaptation efforts continue to evolve across different projects, different classes of owners (public and private), and different locations.

TVD is another attempt to adapt TC to the construction industry, however, the applications of this approach have been limited and further studies must be conducted. This paper examines the real estate development sector using TVD theory in order to identify potential uses for TVD and its key concepts. Several recommendations are proposed based on the data determined by analysis of specific companies and a literature review. The authors' intention is to further develop discussions on the TVD topic. Oliva (2014) also brought contributions regarding the TVD for different types of projects, owners, and cultures. Both studies show that the adaption for real estate development and residential construction is possible with some adjustment. Unfortunately, the lack of qualification, understanding and training on lean thinking and Target Costing/TVD topics is a critical barrier to the full use of TVD and its adaption into other areas of construction.

A full research agenda is required to thoughtfully study the key concepts highlighted from Denerolle (2013) and understand how these concepts can be translated to and used in a new context. Quantification and hierarchy levels can be used in future studies to better prioritise the work needed to be completed and additional concepts to be considered.

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ASSESSING THE FEASIBILITY AND USE OF TARGET VALUE DESIGN IN SOUTH AFRICAN CONSTRUCTION

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ABSTRACT

Target value design (TVD) is a management practice that is undertaken to deliver customer needs within agreed performance parameters. However, the norm in construction for many years has been the compilation of costing / estimation data after design is in place. This practice is evident in South Africa construction where the vicious cycle of design-estimate-construction-rework-estimate continues unabated.

Thus, the need for this research stems from efforts to optimise the value delivered to clients without escalating project cost. The phenomenological research design for the study enabled the collection of data through face-to-face interviews of twenty-four construction professionals with a structured protocol. The study shows that aspects of TVD are already in use in South Africa, though not labelled as TVD. The concepts of TVD are not unknown in practical terms in South Africa. What is missing is the full implementation of the system so that the tide of cost overrun that is synonymous with projects will be reduced.

KEYWORDS

Construction, Cost, Target Value Design, South Africa

INTRODUCTION

Ballard (2011) says that target value design (TVD) is a management practice that aims to deliver exactly what the customer needs in terms of value within stipulated project constraints. As a lean construction tool, TVD shifts the basic thinking within a project, from expected costs to target costs (Ballard, 2011, Rubrich, 2012). This tool requires a change in traditional project estimating practice, which is mostly used in South Africa where cost management outcome in construction projects is a problem (Baloyi and Bekker, 2011). A practice that has the ability to negate the proliferation of cost overrun is required in South Africa. Such a practice could reverse the method of estimating costs for specific projects. The cost estimating practice should aim to deliver maximum value to clients by collaboratively designing a project based on allowable

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cost / budget of the client (Rubrich, 2012). In other words, in TVD, the design follows the allowable cost / available money instead of the cost following the design as in traditional cost estimating practice.

Given that the traditional cost estimating practice has, among other, provide situations where client satisfaction are compromised by contractors through opportunism (Emuze et al., 2013), it is important to seek remedy through the lean construction approach that emphasise increasing value and satisfaction delivered to clients. Seeking a remedy thus led to the compilation of a central research question, which says that "is TVD a familiar concept in South African construction, and if yes, would it be practical and feasible to implement it." Thus, the purpose of this paper is to present the findings of an exploratory study that assessed the familiarity, feasibility, and possible application of TVD in South African construction.

The next section of the paper is a succinct discourse on TVD in construction, which follows a highlight of the research method. The findings of the phenomenology study are presented before a discussion on the efficacy of TVD is used to provide a platform for the concluding remarks of the paper.

AN OVERVIEW OF TVD IN CONSTRUCTION

TVD is an adaptation of target costing, which is a Japanese management practice that has been introduced into the construction industry (Do et al., 2014). It is a tool that requires collaborative involvement of clients in discussions that with the project team. This is necessary in order to establish the value required by the client (to ascertain the basis of the design), allowable cost for the agreed value and the schedule of the project (Rubrich, 2012). The tool is aimed at counteracting the down sides of the traditional practice of design-estimate-rework as illustrated in Table 1 (Ballard, 2011, Macomber et al., 2007). Table 1 show that TVD as a tool promote design-estimate-redesign practice, which enables the compilation of a detailed estimate that is in line with the design that can be constructed with available fund. For this practice to succeed, all members of the construction supply chain have to have a say so that rework can be avoided. In essence, TVD as a tool can be implemented within an integrated project delivery (IPD) team model (Rubrich, 2012). As opposed to the traditional practice shown in Table 1, TVD tool requires the establishment of clients' expectations before detailed designs are compiled. Likewise, it requires that constant and transparent collaborative information sharing is stimulated between designers and builders so that expected cost will be less than the allowable cost of a project (Rubrich, 2012).

Table 1: TVD versus traditional practice of estimating project cost

TVD	**Traditional practice**
Design-estimate-redesign	Design-estimate-rework
First a detailed estimate is built up then a design is made in line with the estimate	Architect/civil/structural designs are drawn up then an estimate is built up
Design is based only on what is possible to construct	An evaluation of the design for constructability might be necessary
All designers are involved from the initial design (architect, engineers, landscape…..etc.)	Architect designs then the other designers base their designs on the architect's design

Sources: (Macomber et al., 2007, Ballard, 2011)

However, it is notable that there are basic elements that have to be in place before TVD can become an effective costs control tactic. These elements include (Macomber et al., 2007):

- Promote extensive consultation with clients to determine the target value.
- Ensure the design team constantly leads the way in learning and innovations.
- Base the design on a detailed estimate.
- Ensure collective planning of execution so that work packages are ascertained.
- Approve completed work based on design.
- Ensure the design follow the sequential order of construction.
- Work in small a manageable team that allows varieties of views.
- Work in a room big enough to house all the teams.
- Constantly review work done and create an environment advantageous to reviews at random times.

These concise explanation on TVD indicate that it is a tool that creates a common financial goal that rely on teamwork; and allow the team to evaluate activities with the sole aim of eliminating waste in the design-estimate-re-design continuum (Rubrich, 2012). It is equally reported to be a catalyst for project success when teams work together collaboratively without relying on traditional practice of design-estimate-rework (Macomber et al., 2007). Beyond collaboration and transparency, TVD could engender a range of benefits (Table 2). As an illustration, it is often an uphill task to obtain accurate working cost of a project. But such project cost could be compiled to align with market price so that the final product would be competitive. In fact, the tool could enable the calculation of credible financial feasibility for building projects.

Table 2: The reported 'pros and cons' of TVD

Advantages	Disadvantages
The costs are worked to be contained within the market price, making the product competitive	It is very difficult to obtain working accuracy of the target cost
There can be no loss upon realisation of the cost goal to achieve within the selling price	Essential costs may be compromised and lead to loss. These compromises may come with the anxiety to contain costs within target
More credible financial feasibility can be calculated	Incurred costs may be different, leading to under or over costing

Source: (Ballard, 2011)

Given the clear and collaborative environment in which TVD could flourish, it is used within an IPD project (Rubrich, 2012), and it is feasible when clients are willing to engage the project team in design and construction processes to ensure appropriate controls are in place. The literature even shows that TVD could be incorporated into other methodologies, apart from IPD. A broader application of TVD known as whole-life TVD arises from the integration of life cycle costing (LCC) and TVD. This approach involves facility operation and user cost, beyond first costs. This broader application encourages comparison of LCC impacts of design alternatives at the design phase. The approach provides project actors with the monetary information on the trade-offs between design and operational decisions so they can make design decisions that improve LCCs (Ballard, 2011).

Therefore, studies have shown that TVD provides an 'integrated' method to facilitate a collaborative LCC assessment process by increasing the level of shared understanding and communication among stakeholders when the method is used iteratively (Russell-Smith et al., 2015).

METHODOLOGY

The location of this study is Bloemfontein in the Free State province of South Africa. The primary data were collected from 24 professionals who were employed by construction firms and consultancies in Bloemfontein. The interviewees include four architects, five contractors, ten quantity surveyors (cost estimators), and five project managers, who were purposively selected based on their project involvements. Interviews were requested and scheduled based on the availability of the interviewees. The face-to-face interviews were conducted at the offices of the participants in the month of August 2015.

All interviews were tape recorded, transcribed and entered into field notes. The interviewees were all university graduates that are exposed to project costing in their professional practice in the construction industry. Twenty-one of the interviewees have been in the industry for over 5 years and six of them have more than ten years of active work experience in the industry.

The interview protocol was structured and it comprises of three sections. Section one was about background information while sections two and three addressed the research questions of the study. The use of a structured protocol is appropriate in this study because it enhances responses to pre-determined insights from the literature, apart from it potential to assist in the compilation of logic models, if such models are required (Gugiu and Rodriguez-Campos, 2007, Grindsted, 2005).

THE DATA AND RELATED DISCUSSION

As mentioned earlier, the research questions guided the interviews and the sub questions that were asked relied on the findings of the literature. As a start in each interview, an explanation and definition of TVD was provided to interviewees so that ambiguities could be eliminated.

The description of TVD as a management practice that aims to deliver exactly what the customer needs in terms of value within the project constraints of cost, time, regulations, and location (Ballard, 2011), was used in the interviews as it was inserted at the start of section two of the structured protocol. The costing related lived experiences of the interviewees were recorded and are herein presented sequentially.

Question 1: What management practice do you use to deliver exactly what the clients in your projects demand?

This broad question was used to assess the knowledge of TVD among the interviews. Three sub questions assisted in the discovery of the extent of knowledge among the interviewees. These questions asked the interviewees if they know what target value is (S-Q1), if they have heard about the term 'TVD' before the interviews (S-Q2), and if they have used / encountered the application of TVD on their projects (S-Q3).

These sub questions were derived from Table 1 of this paper by mixing the attributes of both TVD and the traditional process of project estimation. Table 3 shows that slightly more than half of the interviewees perceive that they do know what TVD is and they have heard about it through readings incidental to continuous professional development (CPD), for example. However, it is notable that only seven interviewees opine that they may have encountered TVD on their projects. These observations show that the ideas of TVD may not be totally novel to the interviewees. In terms of knowledge of TVD, the interviews indicate that awareness is not so limited in South African construction that is yet to embrace lean construction in practice.

Table 3: Perceived knowledge of TVD among the interviewees

Category	**S-Q1**		**S-Q 2**		**S-Q 3**	
	Yes	**No**	**Yes**	**No**	**Yes**	**No**
Architects	3	1	4	nil	3	1
Quantity Surveyors	5	5	6	4	1	9
Contractors	2	3	3	2	2	3
Project Managers	3	2	3	2	1	4
Total	13	11	16	8	7	17

Question 2: Based on your current management practice in construction projects, please select the practice that you mostly encounter in the box below? Please click either a yes or no.

The responses to the sub questions of Question 2 are tabulated in Table 4. The questions were compiled through the use of the advantages and disadvantages of TVD shown in Table 2. The table is informative and it sheds more light on the perceptions expressed in Table 1.

In particular, while most of the interviewees (19 of them) were of the opinion that they practice design-estimate-re-design, their thinking may be on the traditional approach as opposed to TVD. This insight is supported by the fact that only six of the interviewees agreed that a detailed estimate is built up before detail designs are compiled. Following the estimate-design continuum is akin to the intent of TVD and most of the interviewees do not practice such approach.

In addition, Table 4 shows that 'design based on what is possible to construct' are split into two camps within the interview sample and a similar trend is recorded for the involvement of all designers from project initiation. More notable is the fact that almost all the interviewees (20) appear to identify with the 'design-estimate-rework' practice.

The responses to the last sub question also confirm that the current practice of the interviewees tends towards the traditional cost estimating practice instead of TVD given the observation that all of them concur that 'architect designs, then the other designers base their designs on the architects design'. The veracity and / or reliability of the response to sub question 1 in Table 4 by the interviewees require further interrogation.

Table 4: Current management practice among interviewees

Practice	**Responses**	
	Yes	**No**
Design-estimate-redesign	19	5
First a detailed estimate is built up then a design is made in line with the estimate	6	18
Design based only on what is possible to construct	12	12

All designers involved from the initial design (architect, engineers, landscape…..etc.)	11	13
Design-estimate-rework	20	4
Architect/civil/structural designs then an estimate is built up	17	7
An evaluation of the design for constructability might be necessary	16	8
Architect designs then the other designers base their designs on the architects design	24	0

Question 3: Based on your current management practice in construction projects, please select the outcomes that you mostly encounter in the box below? Please click either a yes or no.

Given that the perceptions illustrated in Table 4 tend towards the traditional practice, the observations tabulated in Table 5 can be deemed to be supportive of previous comments. Table 5 shows that in general, the interviewees agreed that actual costs differ from initial projections at the starts of projects, although costs are mostly compiled based on market prices. Also notable is the view that in current practice where design is leading cost (or rather cost follow design), essential cost elements may be compromised to the detriment of the interest of the project and even the client. The other outcomes are also significant as most of the interviewees were in agreement with them, especially when one has to consider the difficulty involved in making sure that target cost is accurate.

Table 5: Outcomes of current management practice as perceived by interviewees

Outcome	**Responses**	
	Yes	**No**
The costs are worked to be contained within the market price, making the product competitive	20	3
There can be no loss upon realisation of the cost goal to achieve within the selling price	17	7
More credible financial feasibility	17	7
Very difficult to obtain working accuracy of the target cost	16	8
Essential costs may be compromised and lead to loss. This may come with the anxiety to contain costs within target	19	5
Incurred costs may be different leading to under or over costing	21	3

Table 3-5 shows that although most of the interviewees are using the traditional practice of project costing, there is a possibility for a shift in practice because they appear to be open to elements of TVD in practice.

Question 4: Based on our discussions so far, please indicate your perceptions on the feasibility and implementation of Target Value Design in South Africa by answering the questions in the box below?

Table 6 indicates that it may be possible to implement TVD where the interviewees are involved in a project as most of them (23) were willing to try the tool in practice and a majority (21) perceive that its application is feasible. In fact 20 interviewees note that they would recommend it to prospective clients, although 17 of them recognize the difficulties that would accompany a change in common practice. In general, only three interviewees say that TVD may not add value to the local industry in Bloemfontein, South Africa.

Table 6: Perceived feasibility of TVD use in South African practice

Query	Responses	
	Yes	No
Would you be willing to try out this method	23	1
Do you think it is feasible	21	3
Would you recommend TVD to a client	20	4
Do you believe it is difficult to change common practice?	17	7
Do you think TVD would add value to the local industry?	21	3

Beyond the 'yes or no' questions, the interviews were requested to comment in broad terms on a range of questions. One of such questions put forward to them was to gauge their opinion about the criticality of factors pertaining to cost, duration / time, and design of a construction project. The feedback from the interviewees was a 50 / 50 split between cost and design. And when further asked to comment on whether one should design to a budget or compile cost to a design, 16 interviewees prefer the former, which is aligned with the intent of TVD. One of the key elements of TVD is for one to design to a budget instead of designing and then costing the design. When this element was posed as a question the results came back as two-thirds of the respondents being in favour of designing to a budget. However, 15 interviewees perceived that the TVD tool would be more suited to private projects. Perhaps, this particular perception is based on the well-known practice of using the traditional / conventional project delivery method for public works in South Africa (Emuze and Smallwood, 2012).

EFFICACY OF TVD IN CONSTRUCTION

To address the efficacy of TVD in construction is to attempt a response to 'have TVD been proven in construction'. This question asked by a reviewer of the abstract for this paper is relevant and it can only be answered by highlighting findings of TVD case studies in the literature. A scan of the literature would attest to the view that most of the case studies on TVD emanate from the USA (Ballard, 2011, Ballard, 2012, Do et al., 2014, Rybkowski et al., 2012, Zimina et al., 2012) and it is only recently that in-roads are been made elsewhere, the United Kingdom (UK) for example (Kaushik et al., 2014). These case studies provide evidence that TVD is a lean construction approach focused on delivering value to clients by promoting a better control over final project cost. In the projects showcased by these case studies, designing to target cost, controlling waste in all forms, and reviewing the design process so as to use various options that reduces time constitute major elements of TVD in construction. Among the case studies, the work undertaken in conjunction with Sutter Health, a client in the USA, provide reasons to further explore the use of TVD in construction (Zimina et al., 2012).

The cost performance of 12 TVD projects (Lee et al., 2011) is at variance with documented cost overrun encountered in similar projects that are not based on TVD – traditional estimating practice, which has been labelled as either planning fallacy or strategic misrepresentation (Bruzelius et al., 1998, Bruzelius et al., 2002, Flyvbjerg, 2008, Flyvbjerg, 2009, Priemus et al., 2008). In one of the case studies, the Fairfield

Medical Office building, recorded an 18.6% actual cost below the benchmark (Zimina et al., 2012). Such performance is a rationale to apply TVD in projects and the preliminary reports from the UK appear to be encouraging (Kaushik et al., 2014). However, mainstreaming TVD would have to overcome certain challenges, which inter-alia include (Zimina et al., 2012):

- The lack of a verifiable basis for client's determination of the worth of an asset and corresponding allowable cost;
- Accurate benchmarking of project cost against market prices, and
- Failure to adjust allowable costs and by extension project budgets in relation to changes in LCC.

In brief, proving the efficacy of TVD is a 'work-in-progress' that is gaining traction as case studies are been reported, not only in the USA, but elsewhere. Through knowledge transfer mechanisms, these case studies could provide grounds for innovative cost management practices in a developing country such as South Africa that must overcome project cost related problems in construction.

CONCLUSIONS

This paper relates the results of an exploratory study on the feasibility and use of TVD in South African construction. In response to the central question of the study, it can be argued that TVD is a relatively familiar concept among the South Africans that were interviewed. Such familiarity may have contributed to the perceptions of the interviewees who contend that it may be implemented in practice in Bloemfontein, South Africa. As highlighted in Tables 3-5, the interviewees were of the opinion that elements of TVD could be discerned though they may not be labelled as TVD in local South African practice.

It is however notable that reported success stories of TVD in the literature is skewed toward particular types of projects (medical /health). Information on wider applications to various project types is needed for evidence based decisions regarding its adoption / adaptation in the construction, especially in developing countries. This reasoning is relevant because project organisation and management in developing countries take place in settings where the decision and action of both internal and external stakeholders with powers that have impact on estimated project cost and the actual project cost is usually unpredictable.

Whereas the study shows the benefits of TVD, which the interviewees were open to adopt and embrace, it should be noted that a change in practice does not come without difficulties. The interviewees recognize this well reported belief and it signals a need to take this study beyond the exploratory stage. A first approach is to distribute / disseminate the findings in a practice oriented forum, perhaps a CPD course for professionals, so that difficulties and their origins can be tackled bearing in mind the intricacies of the South African context.

As part of requirement for continuous professional registration, construction professionals such as the category of the interviewees of this study are mandated to keep up to date with emerging trends in the industry by attending workshops and conferences that bear CPD credits. A further research study should also assess the possibility of developing CDP courses on TVD in conjunction with the South African Council for the Quantity Surveying Professions (SACQSP). Additional evidence would also encourage practice and this can be provided with the use of either action research or case studies for doctoral research projects. To kick start this process, the first author of this paper started the supervision of two doctoral studies on TVD. One study is focussed on South Africa and the second study is focussed on Nigeria so that the two countries that form the economic hub of the region can lead the way, if TVD is to be mainstreamed in the near future.

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ARE TIER 1 CONTRACTORS MAKING THEIR MONEY OUT OF WASTEFUL PROCUREMENT ARRANGEMENTS?

Saad Sarhan[1], Christine Pasquire[2], Emmanuel Manu[3], and Andrew King[4]

ABSTRACT

The UK Government challenged construction to achieve 50% faster delivery and a 33% reduction of clients' capital costs by 2025 – prevailing business models won't meet these targets. Eliminating waste from construction design and delivery as advocated by lean ideals is therefore a necessary step towards these goals. However, waste understood simply as the improvement of current processes rather than fundamental system redesign will not be enough. Obtaining a better understanding and conceptualisation of waste in construction is therefore becoming more crucial. One aspect of this is to challenge the apparent coherence of prevailing procurement practices generated by the institutional, organisational, and commercial environments that surround the design and delivery of construction projects. This paper contributes to this by examining Tier 1 contractors and presents examples of practices that open debate on how to challenge prevailing procurement models for construction. Through literature review and interviews, the study discusses the factors influencing the ‘Principal-Agent’ relationship demonstrating how procurement arrangements often mirror institutional forces. These forces do not necessarily guarantee better value services, they are more likely to serve the interests of large industry players with the bargaining power to create new rules (North, 1994). A radically different delivery model, where the client intends to eliminate the management fees and confrontational behaviours of their Tier 1 contractors is described.

KEYWORDS

Waste, procurement, business models, Tier-1 contractors, agency theory.

INTRODUCTION

The UK Government has created a set of challenging construction targets for 2025. These are: 33% lower costs, 50% faster delivery, 50% lower emissions, 50%

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improvement in exports (HM Government, 2013). Prevailing 'business as usual' approaches won't meet these targets. Obtaining a better understanding and conceptualisation of waste, as understood from a lean perspective, in construction is therefore becoming more crucial, in order to prepare the industry for the radical change demanded of it. Certainly, one aspect of this is the consideration of how the institutional, organisational, and commercial environments that surround the design and delivery of construction projects remain coherent even though they pre-dispose them to wasteful practice. (Pasquire et al., 2015). In an attempt to explain this phenomenon of coherence within the prevailing construction business models, this study looks at one aspect, the buyer-main supplier relationship. In particular, the study aims to reflect upon and stimulate debate on the functionality and production effectiveness of Tier 1 contractors (management contractors). This critical review draws upon Agency Theory and transaction cost economics (TCE), as they seem to provide insights into why conflict and adversarial relationships persist. The underlying premise is that if we can understand the cause of coherence and reveal the waste generated as a consequence then the adoption of lean construction may be more widespread. The paper presents a case study where the 'Principle – Agent' relationship is radically different and concludes by summarising the benefits and threats of removing Tier 1 contractors, proposing alternative procurement models that are deemed to be more efficient, based on the insights of UK industry experts.

METHODOLOGY

This study used semi-structured interviews to investigate problems and inefficiencies that persist in construction models and procurement practices. The study adopted a generic purposive sampling approach (Bryman, 2012), also known as judgment sampling. It is a non-random technique that does not demand a set number of participants (Etikan et al., 2016). Instead, it puts the research questions under investigation at the forefront of sampling considerations (Bryman, 2012). Through this approach, the researcher decides what needs to be known, and deliberately chooses suitable participants who can and are willing to provide the information by virtue of their knowledge or experience. Based on these considerations, the study initially targeted two industry experts with more than 20 years of relevant practical experience. Those experts then proposed other participants who have the experience relevant to this study's main research question. Overall, 6 sequential in-depth interviews were conducted with industry experts (3 senior consultants and 3 senior managers and directors working for leading contracting corporations in the UK), until the study reached a saturation state (Bryman (2012). Each interview lasted about an hour, where NVivo 10 qualitative data analysis software was used to facilitate the transcription and analysis of the collected data.

INEFFICIENCIES IN CONSTRUCTION MODELS AND PROCUREMENT PRACTICES

The construction industry is often regarded as confrontational, risk averse, and lacking trust and capacity for improvement (Rooke et al., 2003) frequently attributed to factors such as fragmentation of the industry, obsolete procurement methods, confusing and treacherous contractual arrangements, the highly competitive cost-driven environment, and the sequential organisation of construction processes (Egan, 1998). Zimina and Pasquire (2011) argued that it is not unusual for construction organisations, because of competitive pressure, to rely on making their profits solely through commercial processes and manipulating roles with others, rather than improving production efficiency. Similarly, Chiang and Cheng (2010) identified that, due to the current highly competitive industry, contractors could only make profits if they concentrated their efforts on three issues: (1) procurement of building materials; (2) cash flow management with their downstream supply chain; and (3) planning for and applying for claims.

Other studies have highlighted associated problems and inefficiencies such as opportunistic subcontract procurement practices (Pasquire et al., 2015), the use of unfair or ambiguously amended subcontracts (Greenwood, 2001), and late payments especially in the UK construction culture (Leitch, 1994; Hughes et al., 2000). These practices although underpinned by the drive to reduce costs often have the opposite effect causing parties to safeguard their own financial position (Pasquire et al., 2015), causing margin slippage, adversarial relationships, and costly and time consuming disputes. Furthermore, clients don't realise the exclusion of subcontractors from most of the decisions on design and assessing contract periods and costs can trigger project value-loss (waste).

Wasteful procurement practices have become part of the institution of the construction industry — "the way it does business", creating a need to understand the characteristics, strategies and tactics that are more or less obedient to imperfect institutional and commercial pressures (Sarhan et al., 2014). Pasquire et al (2015) provide insights into the coherence of the current construction model by presenting a model focused on managing contracts rather than managing production. The current study provides empirical data around the critiques of the role and production effectiveness of Tier 1 contractors. This is based on selected responses of interviewees of this study as follows: "*All the work we do, we subcontract it to subcontractors....So we do the management of the scheme. We don't really do much work ourselves. There are elements of labour, but most of the work that we do is just management of subcontractors*" (Site Agent at a leading infrastructure group in the UK, January 2016). This was described in more depth by another interviewee from a different company: ".. *the main 'make-or-buy' decision goes to the buyer...We do not ourselves deliver very much at all. We rely on our supply chain to do much of that. They have the experts. We act as an integrator, our role is to getting all that effort together successfully delivered. But……when it comes to what actually happens out there in the field, most of the time we will not do it ourselves, we rely on our partners or supply-chain partners to do that for us*" (Head of Supply Chain, major UK construction & civil engineering contractor, November 2015).

AGENCY THEORY AND TRANSACTIONAL THEORY

Agency theory is a branch of transactional cost economics (TCE) that aims to devise efficient ways to constrain the opportunistic behaviour of agents (Walker and Wing, 1999). The focal point of Agency theory is the goal conflict inherent when individuals (or organisations) with different preferences, risk attitudes and division of labour engage in a cooperative effort (Eisenhardt, 1989). Hence, the unit of analysis is the contract, the theory seeks to determine the most efficient contractual mechanism governing the principle-agent relationship. According to Eisenhardt (1989), TCE and Agency theory have similar dependent variables; hierarchies roughly respond to behaviour-based contracts while markets correspond to out-come based contracts (see Figure 1). The main difference between the two theories, however, is that Agency theory emphasis ex-ante incentive alignment and efficient risk bearing, while TCE is mainly concerned with governing ex-post stages of contract (Williamson, 2000). Table 1 summarises the similarities and contrasts between the fundamental assumptions of Agency theory and other Organisational theories.

Table 1: Comparison between agency theory's assumptions and other organisational theories (Eisenhardt, 1989)

Assumptions	Theoretical Perspective				
	Political	**Contingency**	**Organizational Control**	**TCE**	**Agency Theory**
Self-interest	X			X	X
Goal conflict	X			X	X
Bounded Rationality		X	X	X	X
Information asymmetry		X		X	X
Pre-eminence of efficiency		X	X	X	X
Risk aversion					X
Information as a commodity					X

Agency theory broadened risk-sharing literature by attempting to resolve two governance problems in the principal-agency relationship where one party (the principal) delegates work to another (the Agent) to perform the work (Eisenhardt, 1989), see Figure 1. At the heart of Principal-Agent theory is the trade-off between: (a) The cost of measuring behaviour; and (b) The cost of measuring outcomes and transferring risk to the agent. According to Walker and Wing (1999), these include both the cost of constraining the agent's behaviour (or of the agent's opportunistic behaviour if the cost of constraining it is higher) and the cost of loss in productivity and flexibility as a result of the constraint. In particular, the theory seeks to identify whether a behaviour orientated contract is more efficient that an outcome orientated contract. Outcome contracts are those that allow customers to pay only when specified outcomes are delivered, while behaviour-based contracts support process and social control. Agency theory conceptualizes information as a commodity that has a cost and can be purchased. Thus, the principal has two main options (Eisenhardt 1989). Firstly, to monitor and discover the agent's behaviour by investing in information systems (e.g. monitoring and reporting procedures, additional layers of management). Secondly, to contract on the outcomes of the agent's behaviour.

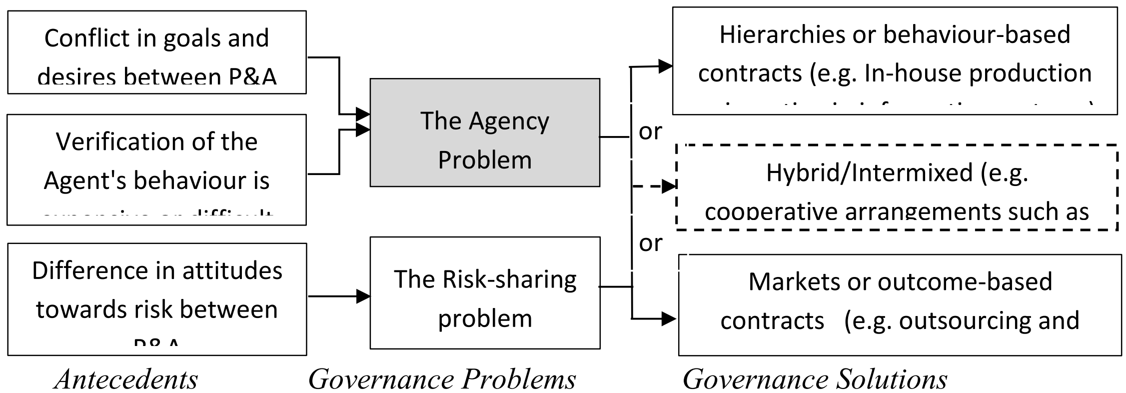

Figure 1: A simplified model of the Principal-Agency relationship problems

This contractual arrangement might motivate behaviour by co-aligning the agent's interests and incentives with those of the principal, but at the price of transferring risk to the agent. Based on the principles of the Agency theory and TCE, Figure 2 illustrates the variables influencing the principal's choice in the form of guiding propositions.

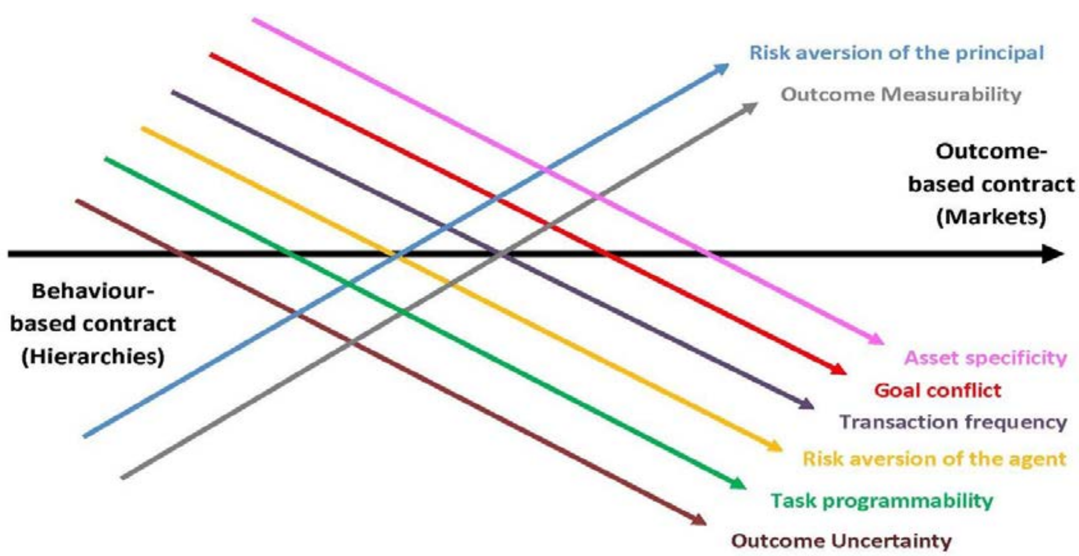

Figure 2: Conceptual model showing the relationship between transactional variables and governance arrangements [modified from Esienhardt (1989) and Paquire et al. (2015)]

THE INFLUENCE OF INSTITUTIONAL FORCES ON CONSTRUCTION PROCUREMENT MODELS

Construction procurement practices are shaped by institutional structures, beliefs and attitudes as well as project characteristics (Sarhan et al., 2014, Pasquire et al., 2015). For instance, unregulated public sector, regulated industry and private building sector practices can provide a contrast in institutional approaches to accountability, the desire for cost transparency, and ways of achieving that through procurement strategies. Thus, it could be argued that construction models and procurement practices often mirror institutional factors. An example of this was identified during the data collection process of this study - *"The (UK) Highways Agency was held up as an exemplar of …improved efficiency in roads management and maintenance. So Local Authorities were then encouraged by Central Government to look at this model. The now limited number of contractors were pleased to extol the virtues of the Highways Agency's model to a local government market which they could also see turning into a market with a limited number of players able to deliver large, integrated service contracts. Local authorities often asked the market (contractors) what scale of efficiencies could be delivered if they were to let a single large integrated manage and maintain contract. The contractors usually came back with the same reply, "20%". There was never any real evidence for this. Twenty per cent seemed to be a figure all the authorities would like to achieve and the major contractors were happy to tell them they could achieve it. So the whole industry created a belief that integrated service contracts delivered by one (Tier 1) contractor with a chain of (Tier 2) suppliers was the most efficient form of delivery..."* (Fellow of the Institute of Civil Engineers (FICE), Senior Consultant, UK, January 17, 2016, E-mail message).

From the words above, it is clear that institutional forces (e.g. 'vested interests' and 'bargaining strength' of major industry players) can have an influence on shaping procurement practices. This argument is supported by North (1994) who stressed that the formal rules within institutions are (normally) created to serve the interests of those with the bargaining power to create those rules. In practical terms, this is also evidenced by the unilateral movement towards large integrated contracts seen in the UK highways sector described above. A change in the status of the Principal is causing new rules to be developed *"... now the Highways Agency has transmorphed into Highways England, a regulated, arms-length government company with greater accountability for costs and performance, Highways England is now recruiting greater procurement and commercial management staff. It is also fragmenting contracts in order to secure greater control and visibility of costs"* (FICE, Senior Consultant, UK, January 17, 2016, E-mail message).

LATE PAYMENT AND THE RESISTANCE TO PROJECT BANK ACCOUNTS

Late payment is a major problem (Proverbs et al., 2000), and a most institutionalised wasteful practice (Sarhan et al., 2014), in the UK construction culture in specific (Leitch, 1994; Hughes, 2000). Historically, it is has not been unusual for lower Tier suppliers, in an industry in which about 99% of businesses are SMEs, to have to wait for up to 100 days to receive payment (Cabinet Office, 2012); due to Tier 1 contractors creating profit from cash flow at the expense of their supply chain (Klein, 2015). This may lead to increased cash flow borrowing, poor performance and associated costs increasing the burden of risk on the supply chain (Leitch, 1994; Klein, 2015). According to the Cabinet Office (2012b), late and unfair payment practices cause 1% - 2.5% of wastage in the cost of projects attributed to factors such as: supply chain members' unnecessary overheads relating to debt chasing and administration, costly payment disputes which ultimately feed back into costs for the client, and potential insolvencies and costs of production losses due to lack of collaboration and trust.

Consequently, Project Bank Accounts (PBAs) were introduced in 2009 by the Cabinet Office in collaboration with public sector clients, as a means to enhancing cost transparency and revolutionising the way members of construction supply chains get paid (Cabinet Office, 2012b; Biddell, 2015). In PBA, supply chain members, do not need to wait for higher Tier contractors to process payment; instead they receive it directly through a bank account specific to the project they are working on, allowing them to concentrate on production delivery (Cabinet Office, 2012b).

Highways England is now using PBAs on all its works, and The Northern Ireland Executive has mandated the use of PBAs, since January 2013, on all construction projects above £1m. Many contractors in the UK are acknowledging that PBAs create a greater collaborative effort along the supply chain. However, some are still battling against their implementation (Klein, 2015). For instance, some contractors argue that PBAs have led to complications with the construction industry tax scheme and VAT; however these claims were ruled-out by the tax authority (Klein, 2015). Klein reported that "*Willmott Dixon went public with their views on PBAs [claiming that:] where responsible payment terms are applied, PBAs are not necessary*" (Klein, 2015). They then criticized PBAs by professing that they are bureaucratic, costly, and onerous for the client. According to Wynne and Hansford (2014), many Tier 1 contractors claim a tedious administrative effort for the management of the multiple accounts in the system adding significant overhead to their businesses. Consequently lead contractors, relying on their bargaining power as major industry players, push for the use of other supply-chain payment arrangements to end the use of PBAs such as Early Payment Schemes and the Fair Payment Charter. However, Klein (2013) condemns the former for being unfair to subcontractors and for reinforcing traditional business models; while the latter can be criticised for its subjective language.

Hansford (ICE past President and former UK Government Chief Construction advisor) said about PBAs: "*Perhaps to a degree it was taking a sledgehammer to crack a nut. I don't regard them as being the panacea*" (Wynne and Hansford, 2014). Instead he suggested widespread adoption of the new charter would remove the need for project bank accounts (Hansford, cited in Wynne and Hansford, 2014). In contrast, Klein (2015) believes that "*if firms are paying responsibly they should not have any issue with PBAs*".

Having reviewed aspects of theory and practice surrounding Tier 1 contractors we now discussed a model that removes them from the construction process altogether.

LONDON UNDERGROUND'S STAKE DELIVERY MODE

With the ambition of cutting costs by 25%, London Underground's (LU's) senior management team decided to cut-out main contractors altogether (Tier 1 and 2). Working directly with specialist subcontractors, they used consultants to supervise the work on the £330m Station Stabilisation programme over a period of seven years (Morby, 2014). Using an apparent lean philosophy 'production leads, everything else enables', they focused their efforts on working more closely with those specialists who actually produce the work. The Stake Delivery Model is a Government Treasury trial project under its Infrastructure UK office (Morby, 2014), designed to deliver the efficiency improvements outlined in the McNulty Report (2011). According to Morby (2014) the Stake Delivery Model key principles include:

- Engaging with the trade contractors and specialists who actually do the work on-site,
- Simplifying contractual arrangements with LU taking most of the risk,
- Providing long term commitments to suppliers,
- Creating a 'one team' approach to project delivery.

BENEFITS AND THREATS OF CUTTING OUT TIER 1 CONTRACTORS

Having provided a brief overview of an emerging construction procurement and delivery model that aims to eliminate the costs of procuring the services of Tier 1 contractors, next we summarise the main benefits and threats of this model based on the insights of UK experts.

Table 2: Main benefits and threats of cutting out Tier 1 contractors

Main Benefits	Main Threats/Challenges
Getting rid of that sort of confrontational litigation that often occurs towards the end of projects	Requires appropriate commercial alignments and conversations at an early stage, to avoid double man-marking of trades under cost-reimbursement contracts.
Reduces overall cost as client now pays the subcontractors directly. Thus, eliminates perceived inflated costs due to 'margin on margin'. i.e. the Tier 1 contractor has a margin to make on top of the margins the Tier 2 suppliers make. Also transfers advantage of competition perceived to be locked into Tier 1 frameworks.	Increases client risk e.g. oversight management of the H&S issues - the client now becomes the Principal Contractor (under UK CDM Regs) and has the overall responsibility for safety. Also, client becomes responsible for managing the interfaces between activities carried out by different sub-contractors and the risk with the overall delays. Similarly, if there are gaps in the design or in the scope of the supply, there is no one for the client to blame other than themselves and thus the client has to pay for it.
Allows client to use smaller contractors creating innovative opportunities to value engineer and collaborate.	Few clients have competencies to manage the works/sub-contractors or have a good knowledge of construction activities/suppliers/the market. Client team will need to employ new people to build expertise which is time consuming and can be costly.

CONCLUSION AND RECOMMENDATIONS

The Principal-Agency relationship is a typical problem that is deeply institutionalised in our coherent construction business model (Pasquire *et al.,* 2015). Construction procurement models seem to be in contrast with the two options offered by Agency theory. They are mainly concerned with either: (1) contracting on the outcomes of the agent's behaviour; or (2) monitoring and controlling behaviour. Based on Figure (1), it appears that the first option (i.e. outcome based contracts) could be suitable for a commodity market; but it is definitely inappropriate for the nature of the construction industry that is characterised by its high levels of complexity and uncertainty. However, many construction decision makers still persist in adopting conventional procurement arrangements, which stand in contrast to out-come based contracts and increase governance challenges; whilst the use of process and social-based contracts seem to be much less prevalent.

On the reasons for the coherence of the prevailing construction model, work by Pasquire et al.(2015) referred this to a model focused on managing contracts rather than managing production. This study supplements their work by shedding light on the influence of the bargaining power that can enable major industry players (e.g. Tier-1 contractors) to dictate the rules of the game – the way we do business. In this study, the main benefits and challenges of a radically different construction model, which aims to cut-off main contractors altogether, was discussed. Based on the opinions of UK industry experts who participated in this study, it appears that the threats/challenges of this model outweigh its benefits. Alternative approaches worth further investigation include: (1) Procuring Tier 1 management contractors to act as 'Management Agents' based on a small fee in relation to the total value of the product, but an incentive for minimising total product cost could be large in relation to that fee in order to encourage total cost minimisation; and (2) Procuring large Engineering firms based on a 'Design and Manage' responsibility. This approach provides actual producers (i.e. specialist suppliers) with more freedom to value engineer, and it eliminates the role of the Tier 1 main contractor's design coordinator who sits between the site-operations teams and the lead designer.

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SECTION: 4 PRODUCT DEVELOPMENT AND DESIGN MANAGEMENT

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BIM: A TFV PERSPECTIVE TO MANAGE DESIGN USING THE LOD CONCEPT

Hisham Abou-Ibrahim[1] and Farook Hamzeh[2]

ABSTRACT

The excitement to implement BIM in organizations usually faces a quick slump as implementation challenges come to surface. Developing projects on BIM platforms significantly defers from drafting them on 2D CAD, where different types of modeling responsibilities appear. Being object oriented, practitioners need to decide on graphical and non-graphical information of model elements to suit the needs of downstream users throughout the design process; a new task absent in traditional procedures. To face this issue, the industry created the notion of Level of Development (LOD) to guide the development of model's content. LOD identifies the specific minimum content requirements for a model element and its authorized uses at five levels of completeness. However, LOD as it currently stands is more of a descriptive index used apart from the model to ensure common understanding of BIM deliverables among stakeholders, and to guide major contractual aspects. Moreover, the current classification of LOD spectrum is influenced by the traditional approach of design management that considers the development of design from less to higher detailing levels, which is basically the transformation view of design. In this context, this paper introduces a new formulation of LOD as a metric related to design context. Nonetheless, it investigates LOD as a tripod to the Transformation, Flow, and Value (TFV) view of design. The research builds on current LOD related literature and introduces three variables to describe LOD based on actual design status. Results highlight the importance of relating LOD to design context, and defining what LOD variables are contributing to the overall LOD value. They also strengthen the role of the new LOD understanding in better navigating design under the TFV approach and enhancing the overall project value.

KEYWORDS

Building Information Modeling, Level of Development, Transformation, Value, Flow. .

INTRODUCTION

The management of the design process is gaining more attention from the lean community. The nature of design, in addition to the impact design solutions and deliverables have on

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construction, operation and maintenance phases, are becoming clearer (Tilley et al. 1997; Ballard, 2000; Koskela et al. 1997). However, the application of lean theories in design, basically the TFV view and the Last Planner (LP^{TM}) system, is inspired by their implementation in construction; the fact that hinders their full integration (Bolviken et al. 2010; Freire and Alarcon, 2000; Koskela et al. 1997). Basically, these theories are employed to plan, schedule, and control **Design Activities** as per lean principles. This study investigates the implementation of the TFV theory from a different perspective focusing on the **Design Product** instead of design activities. The study benefits from the advancements of Building Information Modeling (BIM), and employs the Level of Development (LOD) concept to address the TFV application in design.

The proper management of design requires understanding and accepting its nature by all involved stakeholders. Design is an ill-structured process that does not have a clear destination and a clear path towards that destination. Had the design outcomes been recognizable early on, the design process would not be an adding value process (Ballard, 2000). In this context, design iterations are not only inevitable, but also necessary for designers and clients to better understand their project and increase its value (Reinertsen, 1997). Therefore, the iterative and multidisciplinary nature of design plays a major role in complicating its management, especially because detecting negative iterations and eliminating them is not easy. This fact remains true regardless of the platform running the design process. Whether using traditional 2D-CAD or BIM tools, the chaotic and vague nature of design is always a challenge.

Moreover, design should be understood at its micro and macro levels. At the micro level, design can be seen as a technique used by the designer (Architect, Engineer, etc.) to first formulate the problem, and then find ways to solve it under a set of constraints. This is the cognitive and creative nature of design (Kruger and Cross, 2006; Cross, 2004; Dorst and Cross, 2001). At the macro level, design takes place in a social environment that joins a number of stakeholders with different interests and experiences. This is the process nature of design. Meanwhile, the industry lacks managerial tools that can simultaneously address the micro and macro dynamics happening while the design is unfolding. This is an additional cause behind sub-optimal design management.

Recently, the construction industry is witnessing a new technological shift towards the implementation of Building Information Modeling (BIM). BIM could be described as an n-dimensional compilation of parametric data into central or combined local models. The proper adoption of BIM helps streamline design workflows and facilitate coordination among disciplines in a 3D environment (Barlish and Sullivan, 2012; Eastman et al. 2009; Hartmann, 2010). However, the definition and use of BIM are not stable yet and are far from standardization (Miettinen and Paavola, 2014). The use of BIM as a life-cycle management process is lagging behind its use as a production tool. Since BIM software are product oriented and do not necessarily impose procedural changes in design management, some practitioners switched from using 2D-CAD software to BIM software without changing the work process. Thus, BIM tools revolutionize the product design without necessarily guiding the design process.

To facilitate the use of BIM as a work process, research and industry efforts created the notion of Level of Development (LOD) to formalize the development of BIM models and authorize their possible uses (The American Institute of Architects, 2013; BIMForum, 2015). LOD, as defined by the American Institute of Architects (AIA), defines the minimum content requirements for a model's element and its authorized uses at five progressively detailed levels of completeness. Current classification systems range from LOD 100 to LOD 500, specifying the minimum graphical and non-graphical information an element should hold at each level, and its possible authorized uses. In this regard, LOD is viewed as a linchpin to BIM laying between the system of information deliverables and their descriptions on one side, and the corresponding contractual agreements and responsibilities on the other (Hooper, 2015). However, academics and practitioners have expressed several concerns around the LOD concept as it is currently understood and used. These concerns include:

- The fact that LOD is managed outside the BIM model and is labor-intensive (McPhee and Succar, 2013).
- Current classification systems are limiting the potential of the LOD concept since only five levels are used. This resembles the trial of painting a complex pictures with five colors allowed (McPhee and Succar, 2013).
- Current classification systems can only track elements at LOD milestones without detecting partial LOD levels witnessed throughout the design exercise (at one point, the LOD of an element may be neither 200 nor 300, but somewhere in between).
- LOD values are only descriptive and they are not related to the actual design context where elements pass through different statuses while converging to the desired LOD (for example: under design, pending approvals, design checks, under coordination, etc.).

To address the above mentioned gaps, this study introduces a new LOD framework based on variables related to design context. It also investigates the use of the framework in managing design workflows using the TFV theory. Accordingly, the aim of this research effort is to: (1) define design related variables that describe LOD, (2) link LOD to these variables using an LOD matrix, (3) use the new framework to manage design under the TFV theory.

RESEARCH METHOD AND LIMITATIONS

The research method consists of three stages. The first stage targets the definition of LOD variables based on current LOD related literature and practical guidelines. Three variables: Graphical Detail Level (GDL), Information Richness (IR), and Confidence Index (CI) are introduced to formalize the understanding and use of LOD. While GDL and IR are inspired by current LOD guidelines, CI is used to link the reliability factor of LOD to the actual design context not only to authorized uses set by model authors. The second stage introduces a new LOD-Matrix to link LOD to the defined variables, and the third stage uses the new LOD framework to manage design under the TFV theory.

This effort tries to align the use of LOD in BIM projects with the application of the TFV theory in design management. The LOD framework presented in this paper is only theoretically developed at this stage. Future efforts can investigate the suggested framework on actual design projects to assess its practicality and potentials.

LOD VARIABLES

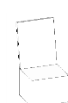
The investigation of current LOD definitions which are primarily inspired by AIA definitions reveals three major components of LOD: graphics, information, and reliability. While an element created in the model gains graphical and information characteristics (depending on how it is modeled and what data is attached to it), its reliability is separately assigned by the designer through the set of authorized uses provided at each LOD level. For instance, the designer can assign a low LOD level, say LOD 200, for a lighting fixture pulled from a library with high graphical detailing and with specific design data, to govern its downstream use by other stakeholders. LOD in this context helps designers communicate their model's content while imposing use restrictions.

Accordingly, three variables are introduced in this study to describe LOD and relate its value to the actual design context: Graphical Detail Level (GDL), Information Richness (IR), and Confidence Index (CI). While GDL and IR requirements can be associated with AIA definitions or other LOD classifications, CI is determined by the type of checks and coordination performed on a certain element, not only its authorized uses. Thus, LOD in this study is not only used as a modeling guide, but also as a design related metric. The LOD variables and LOD-Matrix are detailed in the following sections.

GRAPHICAL DETAIL LEVEL (GDL)

GDL targets the graphical representation of a model element. Four different graphical grades: schematic (G0), generic (G1), defined (G2), and rendered (G3) are adopted according to the UK BIM protocol described in Table 1.

Table 1: GDL variables: grades, description, and graphical representation

Grade (G) (AEC UK BIM Protocol V 2.0, 2012)	Description (AEC UK BIM Protocol V 2.0, 2012)	Graphical Representation
Schematic (G0)	2D symbolic representation of model elements without 3D modeling/ or masses/or derived from other elements.	
Concept/Generic (G1)	Simple place-holder with absolute minimum graphical detail level to be identifiable, e.g. as any type of chair	
Defined (G2)	The element is more precisely modeled and sufficiently detailed to identify type of chair and element materials	
Rendered (G3)	The element is modeled in a realistic manner. This type of representation is usually done by manufacturers	

INFORMATION RICHNESS (IR)

Information Richness (IR) describes an element's richness in non-graphical information. IR can be categorized according to the type of information attached to the element. Five types of information are used in this paper: identification (I_1), dimensions (I_2), performance/specification (I_3), installation (I_4), and lifecycle/sustainability information (I_5) (Weygant, 2011). These types of information cover almost all possible attributes that can be attached to a model element. Table 2 summarizes different IR categories and their descriptions.

Table 2: IR variables: information types and description

Information Type	**Description**
Identification (I_1)	The information needed to identify the element used in the model (Weygant, 2011) (Ex: Mass, Structural Wall, Architectural Wall, Opening, Door, Duct, Light Fixture…etc.). The identification of elements varies according to design development. E.g., a door at early design stage could just be identified as "D1", however, it could be identified as "Single-Flush_800x2100" at a later stage where the design is being refined. An element not modeled in the model, can also be identified through other elements present in the model (ex: paint identified through walls).
Dimensions (I_2)	The size, shape, and location information that define the geometrical identity of the element used (Weygant, 2011)
Performance/ Specification (I_3)	Element qualification based on industry standards. This information helps the design and specification teams to determine why a product has been selected (Weygant, 2011). Nonetheless, this type of data is essential for major analysis tasks (Structural, Lighting, HVAC, etc.).
Installation/ Fabrication (I_4)	Covers any type of data related to element installation and fabrication. An element can hold information about the responsible contractor or fabricator, cost, installation time, installation procedures, or any other related data (Weygant, 2011).
Operation & Maintenance (I_5)	All data related to building or facility operation and maintenance (Weygant, 2011) E.g., maintenance schedule, replacement time, manufacturer information, etc.

CONFIDENCE INDEX (CI)

CI represents the reliability of each element used in the BIM model. CI is gained progressively with each positive iteration and after passing different types of checks and analyses performed within and across disciplines. The design checking process can be divided into two main categories: (1) reviews targeting client needs vs. building standards and (2) reviews targeting product's in-service requirements (Gray and Hughes, 2001), as highlighted in Table 3. CI can take ten different values (C_1 to C_{10}) according to each review type. The mentioned types are suggested to generally describe the checking process happening at the design stage.

Table 3: CI variables: review types and description

Review Type (Gray and Hughes, 2001)	**Reliability Check Type (Gray and Hughes, 2001)**
Reviews targeting client needs vs.	C_1: Client needs vs. standard or innovative technical specifications. C_2: Compliance with building regulation, planning regulations, health

building standards	and safety law, national and international standards.
	C_3: Building Performance under expected conditions of use.
	C_4: Design validation and coordination among different trades.
	C_5: Building safety and environmental compatibility.
Reviews targeting product's in-service requirements	C_6: Constructability.
	C_7: Permissible assembly tolerances.
	C_8: Failure modes and effects, and fault analysis.
	C_9: Reliability, serviceability, and maintainability of building elements.
	C_{10}: Labeling, warnings, identification, and traceability requirements of building elements.

LOD MATRIX

A generic LOD-Matrix is developed to link GDL, IR, and CI variables to LOD as presented in Figure 1. Accordingly, project stakeholders can agree on specific GDL, IR, and CI requirements at each LOD level to plan and control the development of model elements.

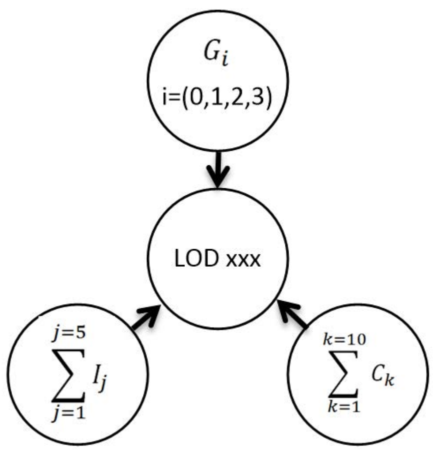


Figure 1: Generic LOD-Matrix

The minimum GDL and IR requirements can be associated with AIA LOD definitions, while CI can be inspired by the corresponding authorized uses. Table 4 highlights the applicable LOD variables for each LOD level as inspired by current AIA LOD definitions. Nonetheless, designers may choose to build their own project specific LODs by specifying a certain combination of GDL, IR, and CI variables.

Table 4: Applicable LOD variables for each LOD level as inspired by AIA guidlines

LOD	Applicable GDL Variable	Applicable IR Variables	Applicable CI Variables
100	G_0	I_1	C_1

200	G_1	I_1, I_2	C_1, C_2, C_4
300	G_2	I_1, I_2, I_3	C_1, C_2, C_3, C_4, C_5
400	G_3	I_1, I_2, I_3, I_4	C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8
500	G_3	I_1, I_2, I_3, I_4, I_5	C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8 C_9, C_{10}

LOD: THE TFV TRIPOD

The new LOD framework is investigated as a tripod to the TFV theory of design management. Each component of TFV is addressed separately in the following sections.

TRANSFORMATION

Several transformation aspects occur during design. While the most general one is the transformation of needs and requirements into the design product, other more specific transformations occur at the level of model elements. Design dynamics, whether at the micro or macro levels, are translated in elements gaining (or loosing) graphical detailing (GDL), information richness (IR), and design reliability (CI). Therefore, the element itself is transforming from one state to another during design. In this regard, the general transformation of needs into the design product can be seen as collective transformations of model elements throughout the design process.

The new LOD framework captures these kinds of transformations. It can track the GDL transformation of an element as more graphical detailing is added, its IR transformation as more design information is revealed, and its CI transformation as more design checks and coordination are performed. Therefore, the framework can track the transformation of a model element at the level of LOD as well as at the level of GDL, IR, and CI variables. For example, a concrete beam planned to be modeled according to LOD 200 requirements will gradually converge to this LOD by a number of transformations. The beam may be first created in the model with GDL of G_0 (schematic) and IR of I_1 (identification). At a later stage, the beam may be generically modeled (G_1) with dimension information (I_2). The element then gains C_2 when the structural engineer finishes the corresponding structural design required at this stage. The beam; however, will not gain C_1 and C_4 unless accepted by the owner and coordinated with other disciplines. Thus, the LOD 200 of the beam will not be attained until GDL, IR, and CI finish their required transformations.

FLOW

A new design flow is defined in this study: the flow of model elements. At every instant of design, some new elements are created, other elements are further developed, and some elements are deleted or changed. Nonetheless, these elements witness several statuses throughout the design process: waiting, under design, inspection, rework, transfer, etc. Therefore, this new flow definition reflects design dynamics and can be used to streamline the generation and development of model elements as well as enhancing the overall design workflow.

The LOD framework is used to describe the flow of model elements and to track their status change over time. Every element can be tagged by GDL, IR, and CI variables, along with corresponding LOD values. In this regard, the design workflow can be addressed as a flow of several categories of elements (partitions, windows, doors, beams, etc.) towards a set of planned LOD levels. For instance, at a certain phase in design, partitions may be planned to reach LOD 300, while doors and windows to reach LOD 200. Design managers can at any point in time check the actual LOD value of an element, define what LOD variables are missing or underdeveloped, and then take adequate actions to remove bottlenecks and keep the element flowing toward its planned LOD.

VALUE

Under the TFV theory, design is perceived as a process that generates value to the customer (Koskela, 2000). In BIM, the customer's value can be directly captured and managed inside the model throughout the project life cycle: from early concepts to the operations and maintenance (O&M) phases. This is in fact the target of BIM use in construction. Practically, customer's value is translated into model elements that evolve during design before converging to a final design product which is the BIM model.

The new LOD formulation targets the value aspect of design by introducing the variables CI. CI includes a set of design checks that target client's value against the corresponding design context (C_1, C_2, C_3, C_4, C_5) on one hand, and against the product's in-service requirements (C_6, C_7, C_8, C_9, C_{10}) on the other. Customer's value then is captured at the level of every model element and can be tracked and managed throughout the design process. Moreover, the new LOD framework serves a self-checking guide used by designers to ensure the quality of BIM deliverables as the LOD of an element is clearly checked against GDL, IR, and CI requirements.

DISCUSSION

A new LOD framework is developed in this study to relate the LOD of a model element to the actual design context. The paper also investigates the use of the framework in implementing the TFV theory in design management. This section discusses the major aspects of the framework and its possible uses.

The framework enables designers build and use specific LOD levels that meet their needs. For instance, designers may agree to model the AC chillers generically (G_1) without struggling with graphical detailing, while providing all necessary data (I_1, I_2, I_3, I_4, I_5) using an online link, and performing all types of design checks (C_1 to C_{10}). This modeling flexibility helps designers better meet client's needs while avoiding over production and unnecessary work. Designers may also use the framework in compliance with current LOD guidelines by aligning GDL, IR, and CI requirement of each LOD level to the corresponding LOD definitions and descriptions.

The purpose of using the LOD classification systems is protected in this study. First, the contractual use of LOD, manifesting in planning LOD requirements and assigning authoring responsibilities, can be associated with the new LOD framework. Moreover, the contract may include specific GDL, IR, and CI requirements for each LOD level. Second, the use of LOD to formalize the development of BIM models and authorize their use is also taken into consideration. The new framework helps in building systematic modeling procedures by setting the specific GDL, IR, and CI requirements of each LOD level.

Designers therefore have clear LOD requirements to be met. Nonetheless, the reliability of model elements is not just controlled by the set of authorized uses; it is clearly related to the design context by the variable CI.

The new framework enables the use of LOD for design management purposes. LOD, as presented in this study, is not just a descriptive index, but also a design related metric. LOD as discussed in previous sections captures the TFV aspects of design from a design product perspective. The transformation of inputs to outputs, the flow of information, and the client's value can be monitored during the design process by tracking GDL, IR, CI, and LOD values of model elements. Accordingly, the use of LOD in BIM projects can be aligned with the application of the TFV theory to manage the design process.

CONCLUSION

This research paper introduces a new LOD framework and uses it to employ the TFV theory in design management. The paper consists of three major parts: the first part introduces three LOD variables (GDL, IR, and CI) related to the actual design context. The second part develops a generic matrix to link LOD to the defined variables, and the third part investigates the use of the new LOD framework in managing design under the TFV theory.

LOD in this paper is presented as a design related metric that changes and progresses over time. The importance of this approach lies in explicitly relating LOD to its GDL, IR, and CI components regardless of the LOD number. Knowing what is actually contributing to the LOD value, in a specific design context, is more important than the LOD value itself. Moreover, the presented framework seems to help design managers better implement the TFV theory in design management. Therefore, The LOD framework can be used to capture the TFV aspects design.

Finally, this research presents a theoretical framework to enhance the implementation of LOD in BIM projects. It also investigates the use of LOD to employ the TFV theory in design. Future efforts can further develop the suggested framework, and can also target its practical application over BIM platforms. Actual case studies can also be conducted in the future to validate the proposed framework and reveals its practical implications.

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AGILE DESIGN MANAGEMENT – THE APPLICATION OF SCRUM IN THE DESIGN PHASE OF CONSTRUCTION PROJECTS

Selim Tugra Demir[1], and Patrick Theis[2]

ABSTRACT

Design phases of construction projects are usually planned and executed using the waterfall model. This type of planning technique is appropriate for checking the feasibility of a project, but not necessarily for managing the work. A dynamic environment requires an iterative management system based on short cycles and rapid feedback loops in order to continuously arrive at the perfect solution. This requirement has resulted in the development of Agile Design Management, which is the adaptation of the Scrum approach into the design phase of construction projects. The goal of Agile Design Management is to increase coordination, interface management, collaboration and transparency throughout all design phases. This paper is an implementation report, also covering theoretical background. Case study data of five projects – as well as images and workshop findings – will be presented and discussed. The success achieved as well as the challenges still remaining will also be examined.

KEYWORDS

Agile, agile design management, Scrum, lean design, waterfall model.

INTRODUCTION

For more than 15 years, Drees and Sommer has been implementing Lean Site Management [LSM] in the execution phase of construction projects. In the meantime, the company has successfully implemented LSM in more than 200 projects worldwide. This has resulted in significant acceleration of construction processes and a reduction in project execution costs of up to 30%. Although the execution phase of construction projects continues to improve, Sommer (2016) identified that the design phase of construction projects is still characterized by:

- Multipage, confusing schedules
- No common understanding of task sequence
- No understanding of other project participant's tasks

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- Delays in planning and information flow
- Long approval processes
- Misconceptions
- Unnecessary functions
- Design failures
- Continuous changes
- Incomplete design deliverables at the end of the design phase

Even if these problems are attributed to the complexity involved in the development of construction projects, there is clearly a need to improve design.

Given this background, Agile Design Management [ADM] has been developed to address the above-mentioned problems. ADM was derived from 'Scrum', an agile management method for software development. The goal of ADM is to increase coordination, interface management, collaboration and transparency throughout all design phases. However, the scope, fragmented teams and complexity of construction projects – particularly during the design phase – do not allow direct adaptation of Scrum from software development. To counteract this, a multi-scrum approach was developed that systematically adjusts to the project organisation and structure. This paper discusses the successful development, implementation and application of ADM. This is followed by a description of the success stories and current challenges in practice.

AGILE IN DESIGN?

The following sections describe how ADM was developed.

THE WATERFALL LEADS TO FREE FALL

Conventionally, all phases of a project are planned using the waterfall model. This type of scheduling is the current best practice, particularly in project management. Ideally, the waterfall model consists of a sequential process in which the scheduler or planner forecasts all activities prior to project start. But the result can only be seen – and therefore evaluated – at the end of the phase. Transparency can be increased by integrating reviews during the phase. However, systematic and structured response to changes is still difficult. There is a clear correlation between change, cost and time. For this reason, the waterfall model is superior to the representation of the critical path or to checking the feasibility of a schedule. The waterfall model is not suitable for managing work and tasks in the design phase, especially in the early stages, such as preliminary design. Forecasting design work prior to project start is challenging, because the design is very vague during the initial stages. Design evolves over time: Only in later project phases does it become clearer what is to be executed or implemented. Early design phases, in particular, need strong coordination and integration. Applying the waterfall model in such dynamic and uncertain environments as early design phases results in most of the processes or disciplines going hand-in-hand, that is, in numerous parallel processes. This in turn transforms the waterfall model into a so-called 'free fall'. This is illustrated conceptually in Figure 1.

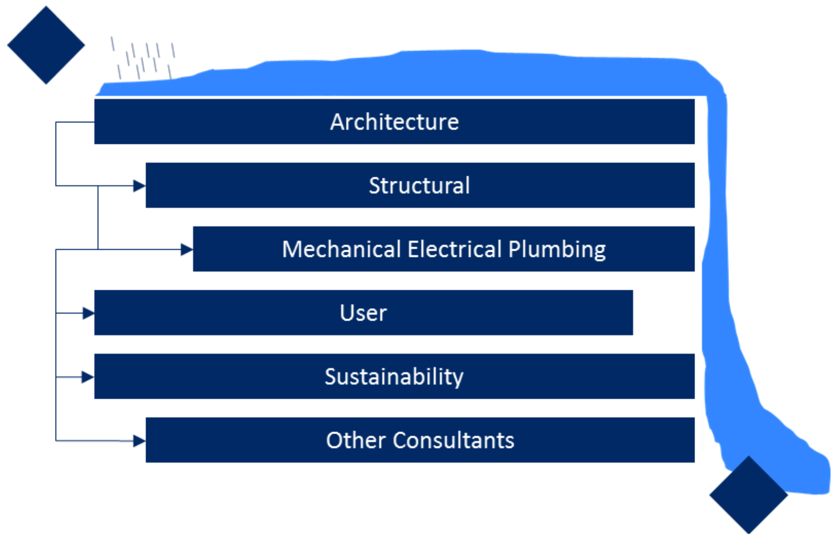

Figure 1: Free fall in the Design Phase

Figure 1 illustrates the difficulty of applying free fall using conventional tools and techniques. It lacks transparency and is unpredictable. This unpredictability results in changes, which in turn cause a dynamic environment. Uncertainty is very difficult to manage with conventional management methods, such as the waterfall model. Adding the high number of design activities and the range of fragmented design disciplines increases the complexity of construction projects during the design phase. For this reason, the current best practice, which attempts to plan design sequentially, is not compatible with the dynamic iterative environment of the design phase.

Iterative vs. Linear

The time for a change in the design process is long overdue. The current 'best practice' must be set aside in order to identify the next practice. In the search for the next practice, Agile Management methods have attracted a great attention in the past (Koskela and Howell, 2002a; Koskela and Howell, 2002b; Koskela et al., 2006; Owen and Koskela, 2006a; Owen and Koskela, 2006b; Owen et al., 2006). The commonality between design in construction and software development lies in their iterative character. In a manner similar to the planning of construction projects, IT development projects use an iterative approach (ibid.). This is illustrated in Figure 2.

The figure below shows the procedure for iterative projects in software development (Wysocki, 2006). As in the design phase of construction projects, a version is progressed and submitted to the client. The client (or their representative) provides feedback. The feedback is then incorporated. In the ideal case, the iterative cycle or this feedback loop continues until the client is satisfied. It has, however, been recognized that current management techniques do not enable project success in software development. Lindstrom and Jeffries (2004) explain that this is because conventional project management methods – such as the waterfall model – improve coordination, but reduce variability and consequently customer satisfaction. Moe et al. (2010) explain that Agile methods have replaced the goal of optimization from conventional models with the goals of flexibility and responsiveness.

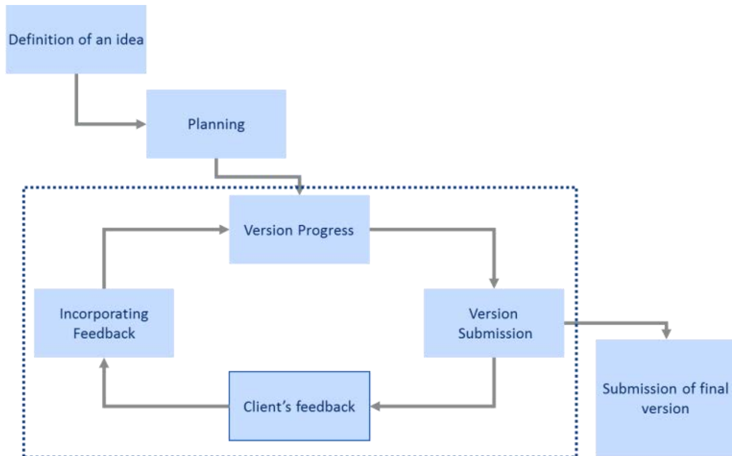

Figure 2: Project life cycle of iterative projects (adapted from Wysocki, 2006)

Agile practices are agile, because they embrace changes, which add value (Hass, 2007). This agility is achieved through feedback loops (Wysocki, 2006), because Agile methodologies assume that variability cannot be reduced, therefore the aim is not to minimize or eliminate change (Highsmith and Cockburn, 2001). Hence the feedback loop allows flexibility and responsiveness, resulting in the ability to respond to change in a systematic and structured way (Hunt, 2006). These feedback loops are called 'iterations' (Chin, 2004; Hunt, 2006; Wysocki, 2006; Fernandez and Fernandez, 2008; Moe et al., 2010; Dingsoyr et al., 2012). The iterative concept of Agile results in a different project life cycle model, as illustrated by Wysocki (2006) in Figure 2 above. In the execution phase of construction, it is desirable to have rigid and stable processes with few changes. However, design is much more uncertain, therefore it is desirable to be agile or flexible to enable systematic and structured response to change. Agile methods focus on the team as an important expertise factor, with the aim of satisfying the client and embracing change (Chin, 2004; Hunt, 2006; Dyba and Dingsoyr, 2008).

What can Construction Design learn from Rugby?

The 'Scrum' is able to satisfy the requirements described above. Moreover, it is the most widely used agile management method in software development and is already used in other industries (Hecker and Kolb, 2016). Scrum is a term in rugby. It is a way of restarting play after the ball has gone out of play. The inspiration for naming the methodology Scrum came by an article by Takeuchi and Nonaka (1986), in which they compared these modern methods with rugby. Scrum was developed by Schwaber and Sutherland (Schwaber, 2004). There is a wealth of literature on Scrum (see for example Schwaber, 2004; Hunt, 2006; Fernandes and Sousa, 2010), and information on the methodology of Scrum can be found there. Figure 3 shows how Scrum works and on which Scrum artefact problems can be found when applied directly to the design phase of construction projects.

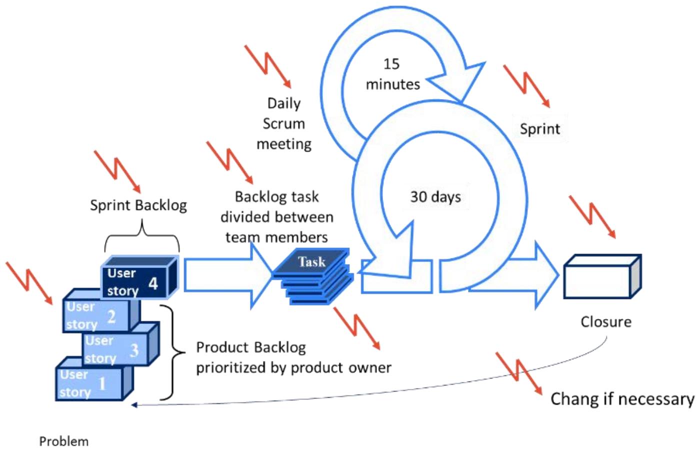

Figure 3: Problems with the direct adaptation of Scrum to the design phase of construction projects

As shown in Figure 3 there are various problems when Scrum is applied directly to the design phase of construction projects. Firstly, it is unclear who the product owner is. If it is the client, the ability to prioritize user stories is debatable. Secondly, in a design phase, there are various deliverables, work packages and tasks. The detail of the user stories in the backlog is unclear, as are the tasks on a Scrum Board. The whole process can become confusing and messy with work packages and tasks. Planning teams usually consist of a range of different disciplines. It is recommended that Scrum not be used with more than 20 team members. This limit can be quickly exceeded even in small construction projects (investment less than €10 million). In addition, the planning teams work in different places, so it is difficult to meet for the daily sprint. Last but not least, design changes are not welcome. With conventional and common design approaches it is almost impossible to divide the project into modules that enable independent processing. Changes are nearly always large in scope and result in increased work for the designers. Even though there are modern approaches such as modularization and standardization, the number of projects applying these approaches is relatively low. It can thus be concluded that the Scrum approach from software development cannot be transferred directly to the design phase of construction projects. It requires adaptations that retain the fundamental principles in a way that the approach is tailored for the design phase of construction projects. The focus needs to be on agility.

AGILE DESIGN MANAGEMENT

Given that the design phase of a construction project is a dynamic environment, an iterative methodology using takt-based work distribution allows complexity to be reduced. This can in turn result in greater effectiveness and efficiency. Even though direct transfer of the Scrum method is not possible, indirect implementation or adaptation can solve many current problems in the design phase of construction projects. Figure 4 illustrates the methodology of ADM.

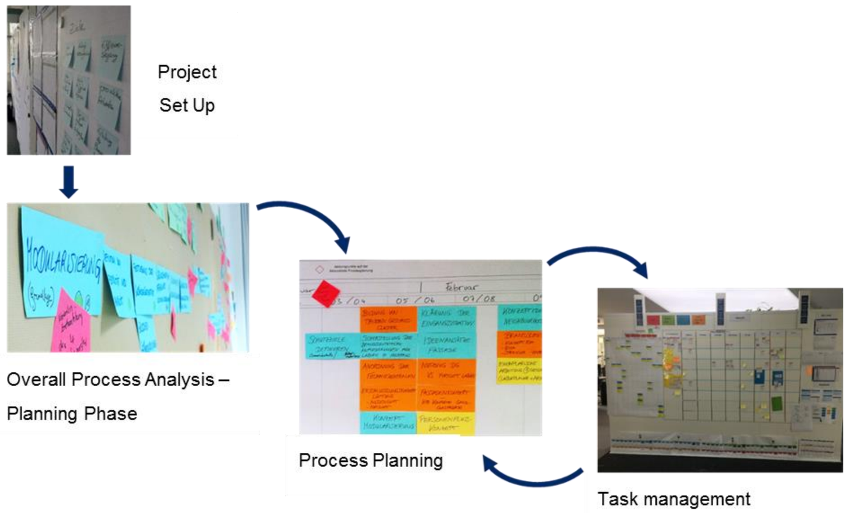

Figure 4: Agile Design Management

Well-known scholars of the IGLC community have provided initial concepts for the potential adaptation of Agile methods from software development into the design phase of construction projects (Koskela and Howell, 2002; Owen and Koskela, 2006; Owen et al., 2006). Previous work established that Agile management methods from the IT sector can be applied to construction design, but not to the execution phase (ibid.). However, none of this research has provided practical approaches for implementation. This gap will be addressed by discussing the methodology of ADM in the following sections.

PROJECT SETUP

Those who want to use Agile need to become agile first (Knittel and Seckinger, 2014). Existing rigid structures do not support the implementation of any Agile methodology. Information flow and instructions must be organized to be in the right place at the right time with the right level of detail. Therefore, the first step is to integrate ADM into the existing structures. In a workshop, the existing project organization is divided into four levels as follows:

Decision-making body

Project management

Planning team

Workgroups and technical planners

The required methods and tools and their level of application are then defined. Depending on requirements, the focus can either be on a design team or on providing a comprehensive solution for the whole project. The results of such a workshop are illustrated in Figure 5:

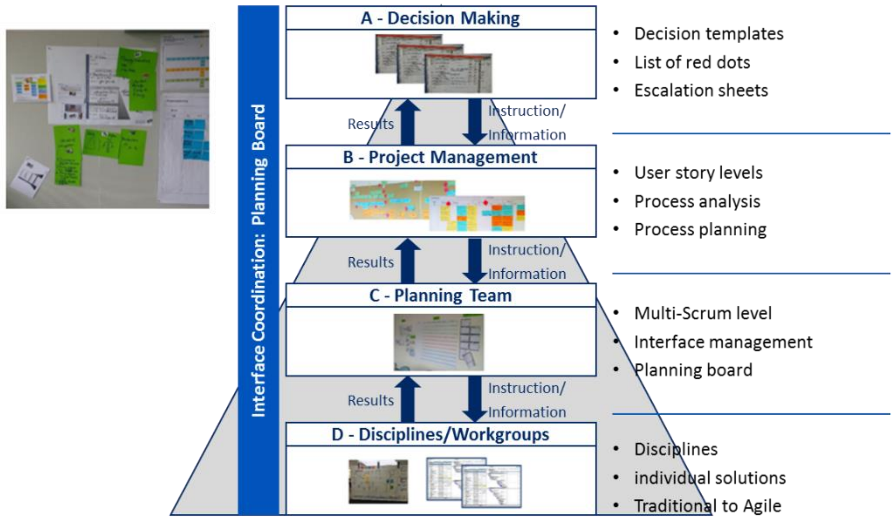

Figure 5: Adaptation of the organizational and operational structure

The levels and the related meetings and workshops are scheduled in a takt-based manner. In the example above, the following meetings were held: a steering committee meeting every three months, a process planning meeting (to identify and prioritize the work packages) every four weeks, and a design team meeting (in front of the planning board) biweekly. In this case study, the planning board – which is derived from the Scrum board – is applied at the design team level. Individual solutions were suggested by the workgroups and technical disciplines. One team agreed to use a planning board and another insisted on using the conventional schedule. This is associated with cultural change. It takes time for all designers to get used to managing and organizing their work with ADM and with their own individual planning board. However, projects usually have tight schedules, so in this project it was optional for the workgroups and designers.

Overall Process Analysis of the Planning Phase

When using the conventional Scrum method, the user stories are defined by the product owner. Unlike software development, design requires a number of experts to design the various properties of the object. The increasing demand for technology in construction projects leads to greater fragmentation and complexity. This makes it very difficult for the client or their representative (project management) to define the user stories.

To solve these problems and define the user stories, workshops with subproject leaders are held to select the content of work packages. The overall analysis of the planning phase process is simply the identification of work packages. These are then roughly prioritized in the same workshop. Examples of work packages are ‘coordination of shafts’ and ‘determining the degree of modularity’. Prioritization of the work packages is performed during process planning.

Process Planning

Process planning defines when each of the work packages must be completed. The prioritization of work packages is done using a time reference. This is usually done every three to four weeks in a workshop with all subproject managers, but workshop frequency is determined by the project participants according to requirements. An overall review updates work packages and checks their end dates. The result of such a workshop is illustrated in Figure 6. When undertaking this workshop for the first time, it is remarkable that the completion dates for work packages are usually chosen to be either at the beginning or at the end of the phase. There are normally no submissions between the start and the end of the phase. This then leads to bottlenecks and transforms the waterfall into free fall, which may result client dissatisfaction. Once the initial results are available, the work packages are scheduled in a takt-based manner, the buffer is eliminated, and interim reviews are integrated. This creates greater agility, allowing the planning team to deploy their own resources better. In addition, action points are identified and included in the 'Red Dot List', which shows issues and risks. The results are then digitized and sent to all the participants.

Figure 6: The result of Process Planning

TASK MANAGEMENT

Each work package has a workgroup. The workgroup defines the related tasks based on the prioritized work packages. The content of the work packages is flexible and can be changed at any time. This is because new tasks may arise as design progresses and existing tasks may become redundant. For this reason, the content of work packages is defined and displayed on the planning board.

Unlike the conventional Scrum in software development, it is very difficult to hold daily meetings for construction design. The different disciplines are usually at different locations.

However, when introducing ADM, the designers have to meet for at least two days in an office provided by the project owner, where the multidisciplinary meetings can be held in front of the planning board. Figure 7 shows such a meeting.

The duration of meetings is immediately reduced. For instance, within the preliminary design phase of a plant project, the regular meetings were cut from five hours to one. This is due to the systematic structure of the meetings. The meetings at the planning board are process-focused. They only deal with tasks that currently have issues. These are marked with a red dot. This high level of focus makes the regular meetings more effective.

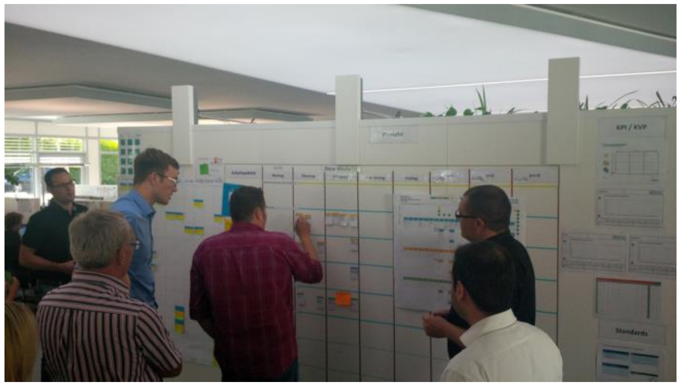

Figure 7: A meeting at the planning board

RED DOT SESSION AS A RETROSPECTIVE

Instead of having discussions on lessons learnt, in ADM the retrospective includes a 'Red Dot Session'. The results of the sprint – such as drawings, reports and visualisations – are printed and presented. All project participants are invited and they have the option of giving their feedback using red dots. A red dot may refer to a problem, a comment, or an action. The results are recorded and the minutes of the Red Dot Session form the basis for the next design phase, for example from the preliminary design phase to basic design phase.

CONCLUSION

By implementing ADM the following improvements were achieved: transparency of in-progress and completed tasks and work packages, collaborative planning of design, joint prioritization of work packages and related tasks, better identification and communication of problems and risks, integration of users and technical departments, coordination of various design disciplines between themselves, rapid escalation of problems through recurring coordinated meetings, increased team motivation through transfer of greater responsibility especially to junior and unexperienced designers, reduction of employee workload and better deployment of resources thanks to takt-based scheduling, and the right level of information at the right time in the right place. ADM uses the principles as well as the artefacts of traditional Scrum. The focus is on the design process itself. So far, the application of ADM is limited to logistics and production facilities as well as office buildings and laboratories. Projects that have to deal with risk and uncertainty, fast-track projects and projects with a strong link between design and execution are those that stand to benefit most. During this study the authors of this paper acted as consultants and did not intervene in the project success.

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CHARACTERISTICS THAT ENHANCE VALUE FOR USERS OF OFFICES—FOCUS ON BUILDINGS AND STAKEHOLDERS

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ABSTRACT

The Norwegian research project OSCAR acknowledges a clear connection between how buildings are designed and operated and which values the business that uses these areas can produce (Bjørberg et al., 2015). This paper addresses what value is for end users of office buildings and how value creation can be optimized from as early on as the predesign phase.

The research is based on a literature review, a case study of an office building, and interviews with two key actors within BREEAM in Norway. The case study includes a questionnaire that had 270 respondents and 8 semi-structured, in-depth interviews.

The design of office buildings has an important impact on the health and productivity of people who work in offices. The study investigates which factors seem to be of most value to end users of office buildings. There are several tools and methods within the project management field that can be used in the predesign phase in order to enhance value for users. The focus in this paper will be on user involvement and sustainability-rating assessment tools. The research addresses why users should be involved in the predesign phase and what to be aware of when involving users.

KEYWORDS

Value, collaboration, sustainability, office buildings, predesign.

INTRODUCTION

According to the literature, office buildings that promote physical, functional, and psychological comfort can contribute to both increased well-being and productivity of employees (Feige et al., 2013, Haynes, 2008). Poorly performing office environments can reduce the value creation of the business because of factors such as lost work hours due to sickness, decreased productivity, a demoralized workforce, and increased staff turnover

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(Clements-Croome, 2015). While Lean Construction has mainly focused on on-site production processes, literature on the topic of Lean Construction argues that the concept of value should cover the whole life cycle of the building (Emmitt et al., 2005, Rooke et al., 2010).

The Norwegian research project OSCAR acknowledges a clear connection between how buildings are designed and operated and which values the business that uses these areas can produce (Bjørberg et al., 2015). This paper addresses what value is for end users of office buildings and how value creation can be optimized from as early on as the predesign phase. In this paper, the terms users and end users refer to employees. Definitions of the terms value and predesign will be discussed as a basis to further answer the following research questions:

1. What characterizes office buildings that create value for end users?
2. How can users be involved in the predesign phase to enhance value creation?

RESEARCH METHODOLOGY

The paper is based on both qualitative and quantitative research. A literature review of relevant themes was conducted in accordance with the procedures described by Blumberg et al. (2014). A case study of an office building was carried out, consisting of a questionnaire that had 270 respondents (response rate of 57%) and in-depth, semi-structured interviews with 8 key actors. The purpose of the questionnaire was to identify how end users perceive value-creating elements in office buildings and how they evaluate these elements in relation to the building they work in. In addition to the case study interviews, two in-depth, semi-structured interviews with key actors within BREEAM in Norway were conducted. All the interviews focused on project management elements such as user involvement and maintaining strategic goals from the predesign phase to enhance value creation for users. The interview procedures were in line with Yin's (2014) recommendations. The interviews were recorded and then transcribed, coded, and analyzed later by the author.

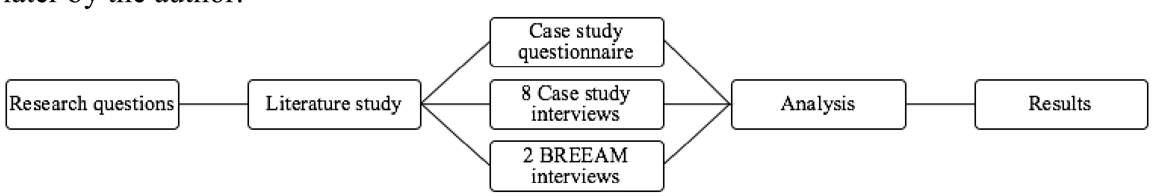

Figure 2: The research process.

THEORETICAL FRAMEWORK

In the following sections, a theory of value creation for users will be presented. There are several tools and methods within the project management field that can be used in the predesign phase in order to enhance value for users. The focus in this paper will be on user involvement and sustainability-rating assessment tools (SRAT). SRAT have been chosen on the basis of the results from the preliminary studies. These results indicated a gap between users' perception of SRAT and the common acknowledgment of the importance of environmental issues.

Drevland and Lohne (2015) acknowledge that value is a complex term that lacks a commonly agreed-upon definition. They refer to Womack and Jones's definition of value in Lean Construction. Womack and Jones (1996) suggest that only the ultimate customer can decide what value is, and value is about meeting the customers' needs at a specific price and at a specific time. Drevland and Lohne (2015) expand on this definition, stating that value judgment is subjective and temporal.

A physical environment that corresponds to the employees' needs and work processes can positively affect their performance, health, and well-being (Haynes, 2008, Feige et al., 2013). On the other hand, a poorly performing office environment can negatively affect the employees' health and productivity (Clements-Croome, 2015).

It is clear from studying lists of qualities that are of value to users that most employees highly value the possibility of doing focused work (individually and in groups) without many distractions. Informal, unplanned meetings are also important (Leesman Lmi, 2015, Brill et al., 2001). According to van der Voordt and van Meel (2000), one of the main challenges in office innovation is finding a balance between privacy and interaction. While distractions are often referred to as the factor that has the greatest negative influence on self-assessed productivity, interaction is often perceived as having the greatest positive impact (Haynes, 2007). Environmental conditions, such as temperature, air quality, noise levels, lighting, and access to daylight, are also of great value to users. Other factors that seem to be important are having information and communication technologies equipment and enough individual space for storage (Leesman Lmi, 2015, Brill et al., 2001).

According to Samset (2010), the predesign phase can be defined as all activities that occur from when the idea of a building is first conceived until a decision to invest in the project has been made. Samset points out that a construction project is at its most flexible in the predesign phase in terms of making changes and that changes made during that time cost less than if they are made at a later stage. He further distinguishes between tactical and strategic performance in construction projects. Tactical performance concerns delivering the agreed project outputs on time and within cost. Strategic performance includes longer-term perspectives, such as relevance, effect, and sustainability. According to Arge and Hjelmbrekke (2012), strategic performance should be strived for in order to enhance value for the project owner and users. They also say that strategic performance includes usability.

By involving users in the predesign phase, professionals can identify their needs and achieve good cooperation (Storvang and Clarke, 2014). The level of user involvement may also have an impact on the users' perceived satisfaction with the result (Baird, 2014). As stated by Hjelmbrekke et al. (2015), one out of three of the main perspectives on why construction projects seem to fail is that user requirements rarely prevail. However, stakeholder involvement is a source of uncertainty, as their motives and actions can affect the project (Ward and Chapman, 2008). Poor stakeholder management may cause cost overruns and time delays (Yang et al., 2009).

Besides involving users in the predesign phase, the use of SRAT, such as LEED and BREEAM, has the potential to contribute positively to users' health and job satisfaction (Baird, 2014). BREEAM and LEED are two equivalent SRAT. Both tools are widely recognized around the world. BREEAM is mostly used in Europe, while the USA, Canada, China, and India use LEED. They provide a broad-ranging assessment of a building's environmental impact and lead to a rating of the building (Reed et al., 2009). Based on their review of literature, Smith and Pitt (2011) list several factors that contribute to productivity among employees, notably personal control, privacy, interior planting, personalization, color, windows, and lighting. They recognize that many of these factors can be linked to considerations in, for example, the BREEAM manuals. Results from a study conducted by Baird (2014) indicate that the overall user perception of sustainable buildings is better than that of conventional buildings, especially when it comes to health and productivity.

RESEARCH FINDINGS

The following sections present the results of the case study and interviews. For the case study questionnaire, 22 factors that could be of interest in the office context were determined. The employees in the case study company were asked to rate the qualities by importance and perception on a 4-point Likert scale. A total of 270 employees responded to the questionnaire (response rate of 57%). The case study interviewees have experience as users, with the predesign phase of refurbishment projects within the case study building, and with the predesign phase of construction projects in general. During initial work conducted as part of the research, it was found that BREEAM was not important to office employees. The interviewees asked about SRAT are among the leading actors within the development and adaption of BREEAM and BREEAM In-Use in Norway.

Table 1 shows the 22 qualities rated by the employees of the case study company.

Table 5: Qualities rated in the questionnaire

Number	Quality	Number	Quality
1	Areas suitable for formal meetings	12	Accessibility and universal design
2	Areas suitable for informal meetings	13	Access to locker room/shower
3	Areas suitable for individual work	14	Facilitation of physical activity
4	Exterior, architectural quality (including outdoor areas)	15	Individual control of shading, lighting, temperature, and ventilation
5	User-friendliness, sense of direction (finding one's way, signage)	16	Arrangements for effective waste management, recycling
6	Workplace design that enables flexible working	17	Indoor climate and comfort (noise, air quality and temperature)
7	Flexibility (possibility of changing area/floor plan)	18	Environmentally friendly, energy-efficient building
8	Modern, forward-looking solutions	19	Interior qualities that promote well-being and orderliness
9	Parking facilities for cars	20	Contributes to pride in the workplace
10	Parking facilities for bicycles	21	Safety and security

11	Availability of public transport	22	Contribution to knowledge sharing and collaboration

The graph in Figure 2 shows how employees in the case study rated the qualities in Table 1 according to how important they are to them and how well they perceive the qualities to be fulfilled in their office building. Based on the mean values, the most important quality to the employees is the availability of public transport. The indoor climate and indoor comfort (noise, air quality and temperature) is the second most important factor, closely followed by areas being suitable for individual work. Also among the most important qualities is having areas that are suitable for formal and informal meetings. Having areas suitable for flexible working is also mentioned as an important quality, but this has a relatively high standard deviation.

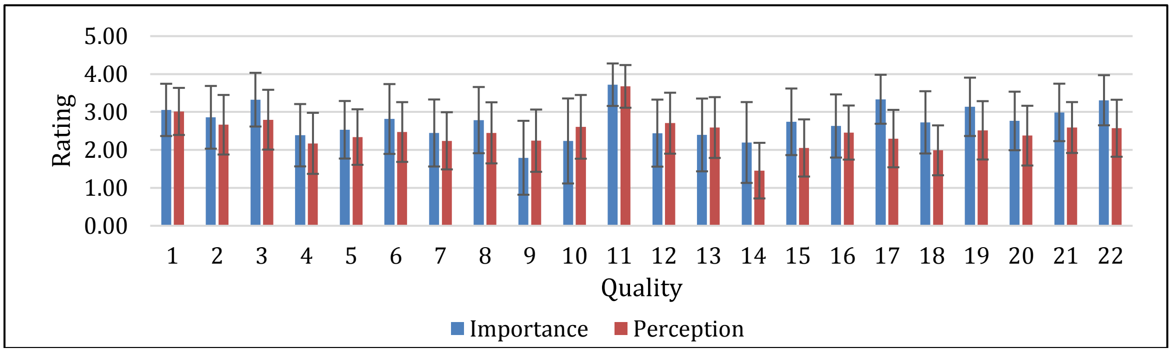

Figure 3: Average ± standard deviation of the qualities listed in the questionnaire.

The case study company rents five floors of an office building in central Oslo. The 1st floor was recently refurbished and has an open-plan layout with a mix of assigned and free seating. The layout is to some extent activity based. The 2nd floor has small, open landscapes with six to eight employees in each room, while the 3rd to 5th floors generally have individual cell offices.

There are several qualities of the office building that the users on the 1st floor, compared to those on the other floors, perceive to be better. These elements are areas suitable for formal meetings, areas suitable for informal meetings, workplace design that enables flexible working, flexibility, modern, forward-looking solutions, and contribution to knowledge sharing and collaboration. Two qualities that are perceived to be better by the employees on the 3rd to 5th floors are areas suitable for individual work and individual control of shading, lighting, temperature, and ventilation. See Figure 3.

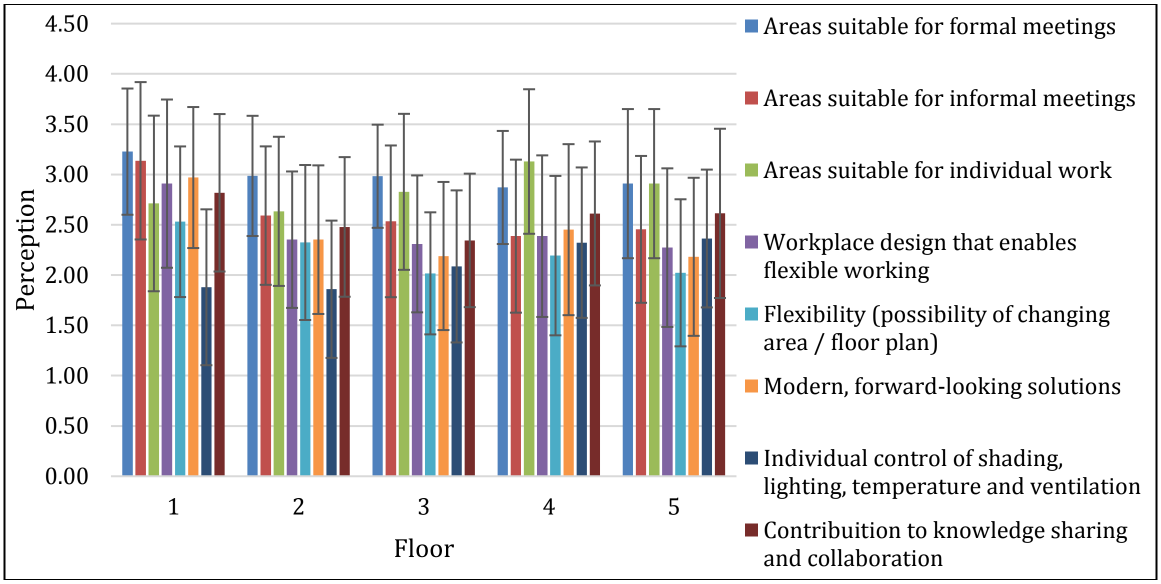

Figure 4: Average ± standard deviation of perception of qualities 1, 2, 3, 6, 7, 8, 15, 22.

The employees were asked to list three things they would like to improve or change. While 6 of the 13 negative comments concerned the indoor environment, those from employees on the 1st floor focused on noise, while negative comments from the 3rd to 5th floors mainly focused on air quality and temperature.

User involvement can be difficult, as users constitute a multifaceted group and have different objectives. However, the interviewees agree that users should be involved if their workplace is to be moved or substantially changed. Understanding the company and the users who will occupy the building is important in order to find solutions that facilitate the core business. Table 3 explains what interviewees consider to be the benefits of involving users in the predesign phase and what the design team should be aware of during the process.

The interviewees agree that it is also wise to involve the company management in the predesign phase, so that they can set strategic goals for the project and communicate these to the employees. This can help motivate the employees and contribute to increased knowledge about what they can expect from the project. Some of the interviewees strongly suggest that certain decisions, such as what kind of office layout will be used, should be made by the organization's management before the users are involved. In that way, some principles appropriate to the management's strategy can be decided first and can be adapted to the users' needs later.

Table 3: Why users should be involved in the predesign phase and factors to be aware of

Why users should be involved	What to be aware of
They feel that they have been involved in the process and that their needs have been taken into account. This gives them a sense of ownership of the office building.	It is important that the users know their role, when they can express their needs/wants, what has already been decided, what they can affect, the criteria for being heard, and to what extent their input will be considered. If they do not, they might be disappointed about what they did not get from the process and the project outcome, instead of being satisfied with what they did get.
Users can have good and/or innovative ideas. They also often know their needs best.	Users often want everything they currently have, and find it difficult to visualize new solutions.
There is often uncertainty and fear associated with change of the office space, so by enhancing the users' knowledge about different solutions they can make better decisions. They understand more of what is happening, and why.	Users often want more than they can have, and it is therefore important to distinguish between general and special needs and wants. Some input can come from few people who speak the most assertively, and vice versa.
Development of new office buildings or office solutions is a maturation process, so it can be an advantage that more people in the organization than management alone talk about such a project.	It is usually sufficient to involve user representatives. However, they should be selected carefully, as it is difficult to satisfy all users' needs by asking only a few of them.
Positive users can promote and assist in the conversation about the project.	If users are involved someone should be there to guide them.
Users who are critical of change can present their views early on. In this way, changes later in the project can be avoided. Involving and informing critical users can also make them be more constructive and feel more satisfied.	People often think that they are special and that general findings from research do not apply to them. There are some variations between employees, but these are rarely so large that they affect the outcome of floor plans.

The interviews reveal that there is a certain degree of user involvement in BREEAM, such as requirements to discuss the needs of end users, identifying and consulting stakeholders, and providing user guides to general users. The interviewees also underline that several of the categories in the BREEAM manual, such as health, well-being, and transport, ensure qualities that can be of value to the end users. When criteria are chosen for buildings that are to be BREEAM certified, it is probably easier to make sure that these are met than when one is dealing with conventional buildings. By reducing qualities, one risks not achieving the required BREEAM score.

DISCUSSION

The findings from the literature review and the research are compared and discussed in the following sections, which are followed by the conclusion, in order to answer the following research questions:

1. What characterizes office buildings that create value for end users?
2. How can users be involved in the predesign phase to enhance value creation?

Both the literature review and the case study indicate that office buildings should support the users' needs relating to well-being and productivity. The case study questionnaire reveals that the most important factors that can enhance value for the employees are basic qualities such as good environmental conditions and areas being suitable for individual work, formal meetings, informal meetings, and flexible working. The literature also mentions technical solutions that support the execution of the work tasks and having enough space allocated for personal storage. For the employees in the case study, the availability of public transport was rated as the most important factor. This might be because the office building is situated in the heart of Oslo and the employees are used to, and see the value of, having good access to public transport. It could also be because their work requires them to travel frequently.

The questionnaire results indicate that several qualities are perceived to be better by the employees who sit in a partly activity-based open-plan space compared to the employees who have individual cell offices. One of the qualities mentioned is the suitability of the open-plan space for informal meetings. However, users who have their own cell office are more pleased with its suitability for individual work. Their concerns with the indoor environment seem to be mostly related to air quality and temperature, while people working in the open-plan space have more complaints about noise. This substantiates the challenge of finding a balance between privacy and interaction mentioned in the literature.

The literature states that strategic performance should be strived for in order to enhance value for the project owner and users. The results from the case study interviews indicate that the company management should be involved in the predesign phase. The management has knowledge of the general needs of the company. Involving them means that they can make certain fundamental decisions before the users are involved and can communicate the project goals to the users. This may help in the facilitation of user involvement, as the users know the purpose of the project and might be more positive about change.

Both the literature and the case study interviewees express the importance of user involvement. It can be challenging to involve users as they are a multifaceted group who might be reluctant to change and have divergent opinions. However, the employees are the people who will use the building. Therefore, if the users' perspective are not included, the project may be unsuccessful in a long-term.

Involving the users may lead to several benefits, such as understanding the users' needs, discovering new solutions, increasing the users' knowledge, and making them more positive about change and the project's outcome. However, as users are a multifaceted group whose motives can affect the project, proper stakeholder management is necessary to avoid time and cost overruns, as well as inflexible solutions that only fulfill certain users' needs. To achieve a successful process for user involvement, it is important to be clear about what the users can affect and when.

The findings from the literature and the interviews with key actors from within BREEAM in Norway indicate that certain qualities that enhance value for users can be ensured by using SRAT. However, which values are covered by the rating tools depends on what qualities and scores the project aims to achieve. The users' needs could therefore be considered when choosing the criteria for the project. The interviewees mention that the use of BREEAM ensures some user involvement. This involvement could be used to help decide the rating criteria.

CONCLUSION

The results from the literature and the case study underpin the idea that finding the right balance between interactions and privacy is a challenge in relation to offices. While there seem to be several benefits of having open-plan and activity-based solutions, cell offices are perceived by the questionnaire respondents as slightly more suitable for individual work that requires concentration. This might be culturally dependent. Qualities that are important to users include having access to areas suitable for different work tasks, a good indoor climate, comfort, information and communication technologies equipment, and space for personal storage.

In order to enhance value creation for end users, this paper recommends involving the business's management and employees in the predesign phase. Some of the case study interviewees suggest that the management should make certain fundamental decisions before the users are involved. The management should state their goals and communicate these to the employees. This can make the employees more positive toward change and contribute to clarification of the expectations for the project. It should also be clear to the users when they can be involved and what they can influence. As the literature recognizes, one of the reasons why projects seem to fail is that user requirements rarely prevail, so employees' needs should be mapped and taken into consideration. This might lead to a more successful project in a long-term, strategic perspective. However, good stakeholder management is necessary, as involving users entails uncertainties.

The literature and the findings from the interviews suggest that the use of SRAT can help ensure certain qualities of value to users, as well as user involvement. However, further research is needed to explore the extent to which SRAT can enhance value creation for end users.

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LEAN DESIGN MANAGEMENT IN PRACTICE WITH THE LAST PLANNER SYSTEM

Roar Fosse[1] and Glenn Ballard[2]

ABSTRACT

Although mostly applied to planning of construction work, projects have also benefitted from adopting the Last Planner System® (LPS) to the design phase. This paper investigates how LPS applies lean principles in design management by presenting a case study of a project changing from traditional planning of the design process to using LPS.

Before the transition, the project struggled with several common challenges in design and was in danger of not submitting the design proposal on time. After implementing LPS, performance significantly improved, with the design proposal not just submitted on time, but also performing very well in terms of customer requirements regarding cost and quality.

It was clearly stated from the design team that they benefitted significantly from LPS. Better team alignment, clearer task description, better sequencing and increased process transparency were some effects, as well as potential problems better identified and solved in time through a weekly plan "check, correct and lookahead"-routine in design meetings.

The aim of this paper is to contribute to the practical understanding of how LPS can be applied to design and what outcomes can be achieved. Previous research has established LPS' potential to counter common challenges in the design process, and the authors hope this paper further strengthens this notion by contributing with additional empirical findings.

KEYWORDS

Last Planner System, Lean Design, pull planning, PPC.

INTRODUCTION

The construction industry has for long shown significant room for improvement (Teicholz, 2001; Ingvaldsen and Edvardsen, 2007; Thune Holm and Johansen, 2006; Kalsaas, 2013). Forbes and Ahmed (2011) claim that the construction industry has for years become less efficient while other industries have improved, and that the industry is in strong need of improving approaches to several central processes.

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Apart from years of improvement potential in the planning and execution of construction, there is undoubtedly potential in the processes underpinning efficient production, such as design management (Haymaker and Flager, 2009). One central aspect of design management is planning and controlling the design process itself. This paper addresses how managing the design process by applying LPS can provide desired outcomes in the design phase through answering the two following questions:

- How applicable is LPS to plan and control design processes in practice?
- What results can be achieved in design management with LPS?

THEORY

LEAN DESIGN

The term "lean design" has for some years been used for the application of lean principles and methods in the design process (Hamzeh et al., 2009). Some characteristics of a lean design process are: A strong focus on early customer involvement, maximizing value by thoroughly identifying customer needs, minimizing waste in the process by early clarification of needs and objectives between project parties, establishing both product design and process design, making design decisions at the last responsible moment and optimizing sequencing of design tasks to reduce rework through unnecessary iterations (Khanzode et al., 2006; Ballard, 2000; Hamzeh et al., 2009).

Furthermore, lean design management often uses modern techniques and tools such as Target Value Design (TVD), Set Based Design (SBD), Building Information Modeling (BIM), Choosing By Advantages (CBA) and the Last Planner System (LPS) as means for realizing lean principles in practice (Munthe-Kaas et al., 2015).

PREVIOUS RESEARCH ON IMPLEMENTATION OF LPS IN DESIGN

Hamzeh et al. (2009) state that LPS is applicable to construction design processes and offer several benefits. Ballard et al. (2009) identify the differences between designing and making things, for instance that design tasks can be reciprocally dependent, and through two case studies present how LPS successfully impacted design work. Although the number is relatively small compared to that of construction work, there are published cases of LPS applied to design processes at least back to 1998 (Ballard, 2000).

In a case study, Kerosuo et al. (2012) observed increased completion rates of design tasks with LPS, with the design team becoming less reactive and more proactive, focusing on discussing interdisciplinary input needed to complete tasks than spending unnecessary time discussing uncompleted tasks. Koskela et al. (2002) argue that projects often realize that LPS is not only a better system for ensuring reliable promises, but that the lack of reliable promising itself had for years been a roadblock for efficiency in all project phases.

LPS can be seen as a system encompassing several components, with each of them being effective countermeasures towards what has traditionally been challenges in design management (Ballard, 2000; Mossman, 2013, Jørgensen and Emmit, 2009):

- **Planning**: Pull-planning sessions involve relevant project participants to create a plan based on needs across the team. Ownership of the plan is increased among participants as people can better explain and solve task sequencing of complex problems with visual post-it plans. This increases transparency of how design work must fit within the available time given by the plans for construction, resulting in plans more likely to be executed.

- **Lookahead**: In contrast to traditional planning, where problems are solved after they arise, one of the strengths of LPS is always focusing on making tasks ready in the coming weeks and solving problems proactively.
- **Checking**: Tracking PPC and root causes for failed commitments provides information on how work actually is performed compared to how it was planned.
- **Learning**: Analysis of PPC and root cause analysis over time provides useful insight into plan reliability trends so that we can implement counter-measures for problems that systematically cause failure to complete tasks as planned.

CASE STUDY

Workplace Oo

Skanska Norway both owns and develops the project, which is an 8-story, 22 000 sq.m., 380 MNOK (approx. $45M) office building in Oslo. The case study took place in the development phase, where initial design was developed within the owner's cost and quality requirements and then submitted for evaluation and negotiations to establish the final project scope. The design team was from several companies and consisted of two bid managers, an owner's representative, an architect, a structural engineer and several technical engineers as well as some specialty disciplines.

From Traditional To Lean Design Process Management

Initially, the bid phase was planned and managed traditionally, with the bid manager planning every design discipline's tasks and trying to control the process. Within a short amount of time, however, several unwanted, although not uncommon, effects occurred:

- **Unclear handoffs and need for input***:* Tasks seemed poorly described and not in the optimal sequence. Several team members felt a number of their assignments were not broken down correctly, and they were lacking input from each other.
- **Little or no confidence in the time allocated**: Fairly early it became a stressed notion in the group that there was not enough time to do the design work. Consequently, the deadline was extended. But, after another few weeks the same situation arose, and another extension was granted. However, when the team argued that a third extension was needed, this was denied by the owner.
- **Low volume of deliveries per week***:* It seemed like the design team continuously fell behind schedule due to a low level of completed work per week. The assistant bid manager had a suspicion that the cause was poor planning and control.

- **Decreasing group atmosphere**: As can often happen in a poorly performing group, the level of incipient friction and poor communication increased.

The assistant bid manager involved his regional lean manager (the lead author of this paper) to establish a new system for planning and controlling the design process. LPS was not specifically requested, but "some sort of post-it planning methodology" was discussed as he had positive experiences with at least putting post-its on a wall. However, the bid manager had experienced an attempted post-it planning session that had not gone too well, which could explain the hesitation to contact a lean advisor.

Due to the state of the process at the time, the lean manager strongly recommended a very structured management philosophy with a few specific focus points that needed to be endorsed by the two bid managers before initiating the LPS implementation:

- **High focus on structure***:* In the design meetings, a clear separation of process discussion (first 30-60 minutes) and design discussion (remainder of meeting) was important. This was to avoid stopping for lengthy design discussions in the process portion of the meeting unless it had significance to the plan.

- **High focus on structure***:* In the design meetings, a clear separation of process discussion (first 30-60 minutes) and design discussion (remainder of meeting) was important. This was to avoid stopping for lengthy design discussions in the process portion of the meeting unless it had significance to the plan.
- **Involvement and equality of disciplines***:* With a clear need for information, clarifications, decisions and deliveries across the team, all disciplines were gathered for the pull planning and the weekly design meetings. Owner and design management were handled as trades, equal to the others and similarly held accountable for the deliveries they had towards the team. An owner representative being faced with the same questioning for commitments as the fire consultant is uncommon and could initially feel uncomfortable, but was essential.
- **Metrics had to be understood and embraced***:* For example, none of the design team members were familiar with PPC. It was therefore critical to introduce this correctly, as an indicator of *to which extent we as a group performed as committed*, not a measure of the quality of work performed and certainly not a metric used to single anyone out.

IMPLEMENTATION OF LPS AT WORKPLACE OO

In the spirit of lean, the design managers and lean manager started by identifying which parts of the LPS were value-adding in the process at hand and which were not. The following choices were made from the conventional LPS:

- **Only one plan level**: For the development phase of nine weeks, there was no need to split the plan into different plan levels. A high level of detail of tasks was chosen, which was consistent for the entire plan.
- **Alternative lookahead process**: As part of the plan check routine in the weekly design meetings, every trade needed to check if all necessary predecessors for their

activities were in the plan. Although more prerequisites might be needed for tasks to be sound activities than what can be presented as predecessors, it was deemed sufficient due to the experience that design commitments usually fail due to preceding activities (drawings, lists, decisions etc).

- **No root cause analysis***:* With limited time for learning and the entire methodology being new to the entire team, this was considered an excess tool.

Pull-planning

The entire design team gathered for a two day pull-planning session. This is longer than usual for planning such a short phase, but there was a need to stop the ongoing process at Workplace Oo, get the team aligned and establish a good plan.

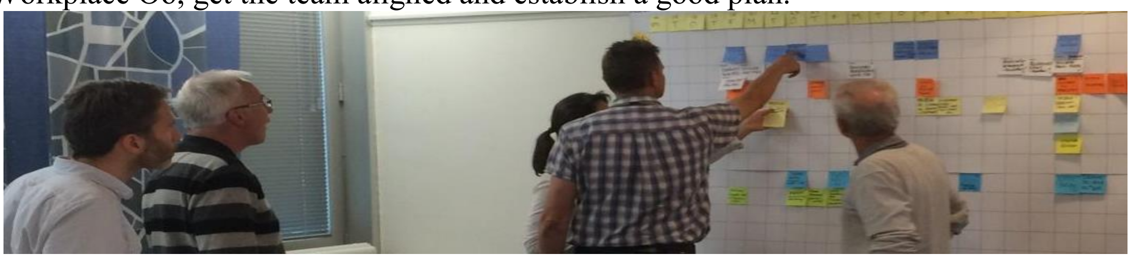

Figure 1: Pull-planning session at Workplace Oo

There were some guidelines used in the pull-planning session:

- Every post-it is an *output,* a "delivery" (e.g. drawing, list, decision) from that person into the group, not an *input* (something the person needs from the group).
- Post-its symbolize the moment of completion, not put over the entire time span work is performed. The latter is usually done for planning production work, to visualize the duration of tasks, which helps in managing logistics and safety by signaling what work is being done when. In design, however, a post-it rather signals the specific moment in time a task is complete (the time of the handoff).
- People can only handle their own post-its. If someone needs another discipline to add or move a task in the plan, they need to ask the person representing that discipline to do so. This creates a high ownership of tasks, as no person could ever say a task has been assigned to them without them knowing and agreeing.

After an initial quick training in lean principles, the session was split into four stages:

1) Writing well-described post-its and putting them in sequence on the wall.
2) Everyone checking each of their own post-its to make sure that all predecessors are to the left of that post-it, generating more post-its if necessary.
3) Marking a "v" in the top right corner of each of their post-its to truly commit to having checked that each post-it has the necessary predecessors. More post-its appear as disciplines feel more obligated to truly check and commit.
4) Post-its are moved from the blank plan onto a plan with rows (time) and columns (disciplines), allowing for more accurate estimates of time needed per task.

Through the entire design process, the plan was accompanied by a question matrix, used for questions that design team members were unable to answer right away and that could not be formulated as commitments on the plan. Questions remaining in the matrix for weeks became very apparent, so these issues were handled quicker than in traditional design processes, where forgetting or delaying a response is much more acceptable.

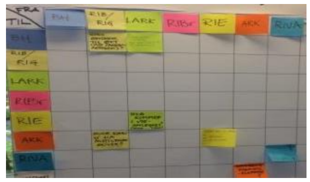

Figure 4: Question matrix at Workplace Oo

Weekly plan check and update

Every design meeting started with a 30-60 minute process section consisting of 3 steps:

- **Plan check***:* Checking the post-it plan if committed tasks are complete (marked "OK") or not (marked "X") and calculating PPC. It was a clear shift in mindset to parts of the design team that "partially complete" was considered "incomplete".
- **Correction**: Incomplete tasks had to be changed from past to future commitments. They could be moved, rephrased (perhaps task definition wasn't accurate enough) or split into several post-its. If other future tasks had to be shifted accordingly, participants owning these post-its would come to the wall and do these changes.
- **Lookahead**: The design team checked if future commitments were realistic. Changes included improving task description, splitting or merging tasks and adding predecessors. Focus was especially on the next few weeks, but this was also an opportunity for discussing issues further down the plan.

This weekly routine was in fact a plan-do-check-act approach to the design process: During the week, the design team worked with their commitments (do), then in design meetings PPC was tracked (check), incomplete commitments corrected from past to future (act) and a lookahead process performed for the upcoming weeks (plan). The question matrix was also checked and updated as part of the weekly plan check.

RESULTS

A successful bid submitted

The design team at Workplace Oo went from struggling to performing very well, going from being in risk of not delivering an acceptable bid within the time to not only delivering the bid on time, but doing so within the accepted cost, breaking records on cost per sq. meter and satisfying all client needs. The project is currently in the final stages of establishing the final project scope before commencing.

Benefits of pull-planning

In reviewing the design phase, pull-planning was considered imperative for establishing a good plan as basis for effective collaboration. This is further supported by findings from projects across the region, where design teams have ranked how they feel pull planning, as opposed to traditional planning, increased the following factors on a scale from 1 to 6:

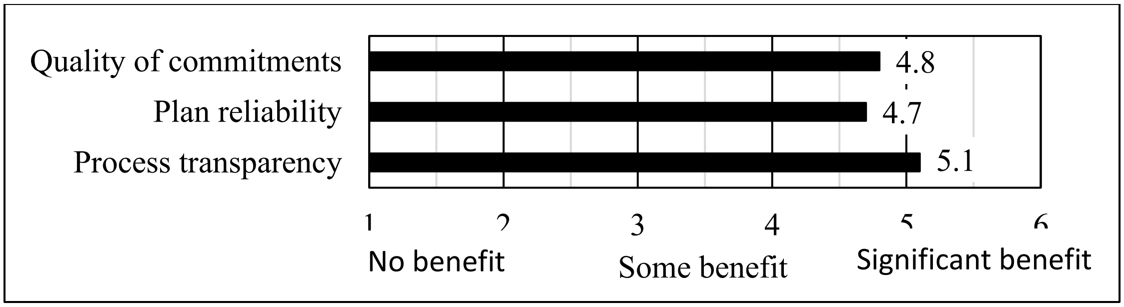

Figure 2: Survey of effects from pull-planning vs traditional planning (60 answers)

Percent Plan Complete (PPC)

The design team at Workplace Oo started with a high PPC. As so often in construction, teams have a good idea what to do in the near future and perhaps somewhat forget the more distant future. Also, the team had even started several of the committed tasks before the pull-planning session, making them very likely to be complete in the first plan check one week later. After 3 weeks of less impressive PPC scores, the design team had an increasing level of average PPC, indicating that they became better at planning throughout the process, finishing with a strong average PPC of 75,53%.

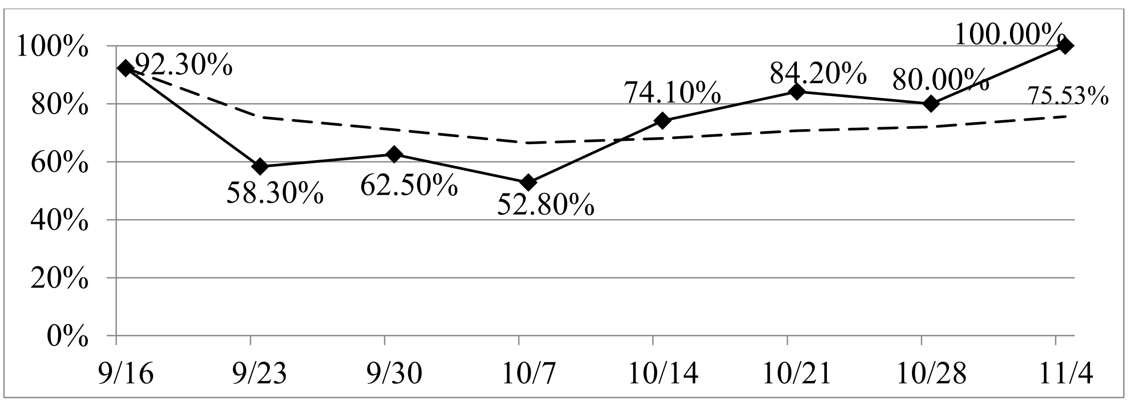

Figure 3: The weekly (solid line and nodes) PPC and average (dotted line) PPC.

Task Completion Curve (TCC)

Although not a tool from LPS, this tool was used to visualize the volume of tasks delivered in the process by breaking a burndown chart (known from the SCRUM planning methodology) down into its two components: Total volume of tasks on the design plan (the number of post-its on the wall) and accumulated number of completed tasks (the number of “OK” post-its on the wall). The Workplace Oo delivery curve (dotted line) shows a stable, even delivery volume per week.

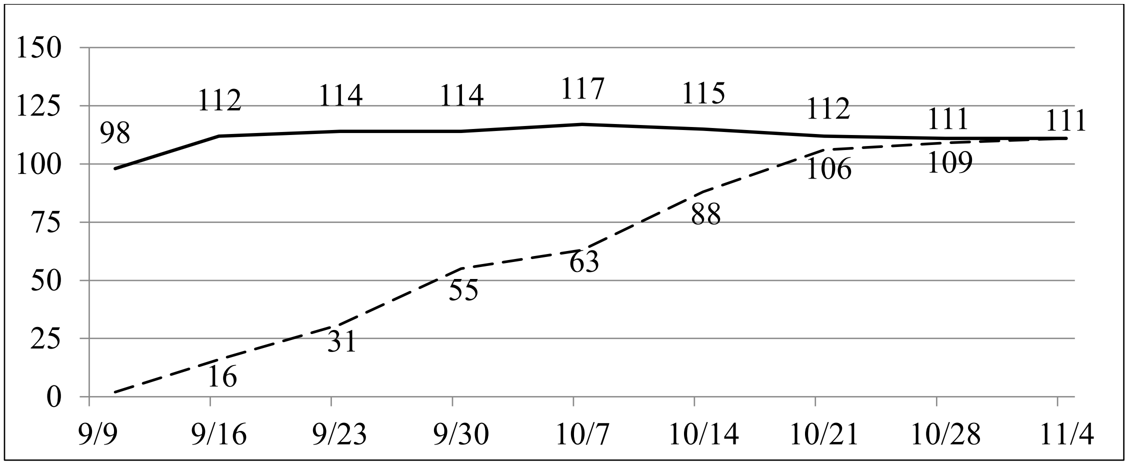

Figure 4: Total number of tasks on design plan (solid line) and accumulated number of completed tasks (dotted line).

Failed commitments

In the weekly plan checks, completed post-its were marked "OK". Non-completions were marked "X", and the number of X's on a post-it could accumulate, since incomplete activities were moved to future commitment dates and being subject to future plan checks. Of the 111 total tasks, the final distribution at Workplace Oo in terms of X's was as follows:

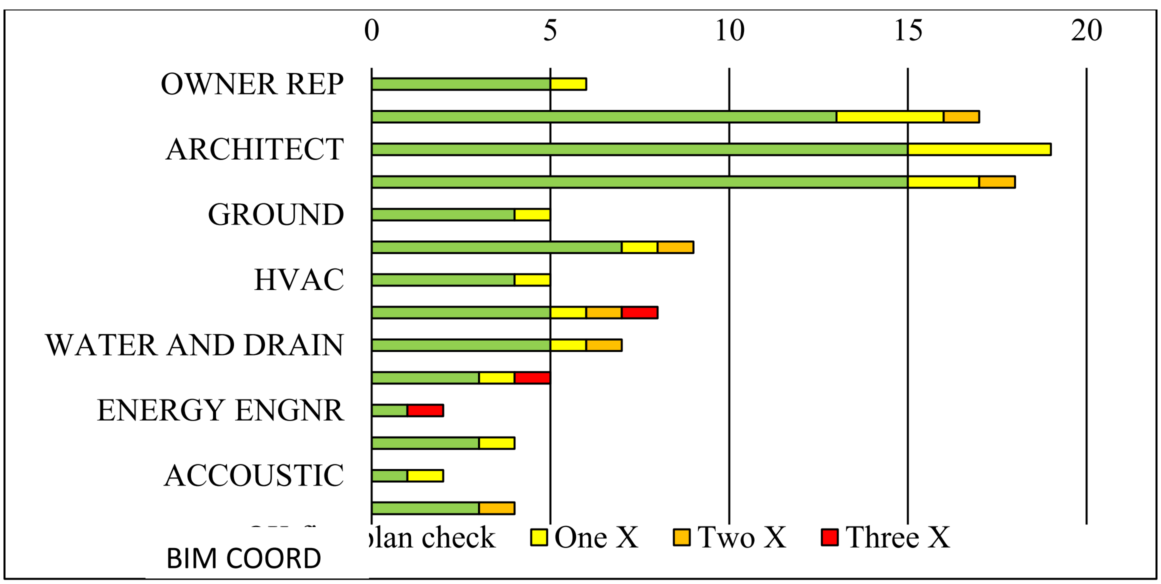

Figure 5: Distribution of accumulated X's of commitments.

This figure shows that overall, most trades had a healthy distribution of tasks completed on the first attempt to commit (green bars) vs failed commitments. It was noted by the design management that the team had gained from the reliable promising of the owner's representative and the architect, which is supported by figure 5.

DISCUSSION

The two research questions posed in the introduction were:

- How applicable is LPS to plan and control design processes in practice?
- What results can be achieved in design management with LPS?

LPS is undoubtedly applicable, with some adjustments compared to planning construction, such as post-its representing the time of handoff rather than visualizing the entire duration of time a task is worked with. The case study did not utilize all the components of the LPS. For instance, only one level of detail for the entire phase proved sufficient, due to the design phase at hand lasting only 9 weeks. Root cause analysis was also seen as an excessive tool for the case study, but it is an ambition to establish this tool for learning throughout the rest of the project. There are no indications that these elements of LPS should not be applicable as well.

The desired effects of applying LPS as outlined by previous literature could definitely be identified as outcomes identified from the case study:

- Increased process transparency, quality of commitments and confidence in plan reliability among design team with pull-planning with post-its.
- Work scheduling from pull of assignments from a client-supplier mindset in the design team, clearly seen in the process of pull-planning with post-its.
- Learning through tracking amount of non-completions and identifying which deliveries struggled to be completed. At the time of submitting this paper, the contractor has implemented LPS as described in this paper on over 10 projects, and by tracking their non-completions, we are hoping to learn *which* commitments projects struggle to deliver on. Root cause analysis has recently been implemented in some of these projects, and will hopefully providing information on WHY these failures in commitments occur.
- Process control was achieved with metrics such as PPC and delivery volume control, giving the design management data to understand if the design process was going in the right direction or if corrective actions needed to be taken.
- Plan-do-check-act mindset through the steps of weekly work planning and plan checks in design meetings.

CONCLUSION

The case study clearly indicates that the Last Planner System® is not only applicable to design processes in practice, but also has very beneficial effects for projects, supporting the findings of previous research. Since some elements of LPS could not be included in this case study, future research should investigate if adding these bring additional benefits to managing design processes.

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COMMUNICATION IN BUILDING DESIGN MANAGEMENT: A COMPARATIVE STUDY OF NORWAY AND GERMANY

Josefine Aasrum[1], Ola Lædre[2], Fredrik Svalestuen[3], Jardar Lohne[4], and Stefan Plaum[5]

ABSTRACT

First-rate communication between design and construction site teams is imperative for the successful completion of architecture, engineering and construction (AEC) projects. Still, research carried out in Norwegian and German industry has identified a lack of literature and qualitative research in this area. Equally, there seems to be a tendency to underestimate the correlation between communication and efficiency in most construction projects.

By addressing different factors affecting communication, reasons for communication, communication networks, communication channels and future needs in a comparative way, this paper aims to increase knowledge about and understanding of communication in the design-construction interface. An extensive literature review, a document study and in-depth interviews were carried out, according to a qualitative approach. The findings are limited to the investigated cases. However, they do imply that there is a need for a better understanding of communication both in Norway and in Germany. Additionally, the research revealed a lack of knowledge and training in the use of ICT tools and team frameworks. By increasing the awareness of the communication challenges that exists, this study can help AEC practitioners and academics to solve communication problems between design and construction site teams.

KEYWORDS

Communication, Design, Production, Collaboration, Flow.

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INTRODUCTION

It is a common apprehension that the overall performance of the architecture, engineering and construction (AEC) industry has declined compared to that of others (Egan 1998; Love and Li 2000). This is typically considered a result of the industry's increased complexity and rapid growth, in response to the more rigid environmental, financial and social goals of stakeholders (Grey and Hughes 2001). A major challenge in modern construction seems to be lack of integration and effective communication between design and construction site teams. Even when participants make significant effort working together, communication difficulties will occur (Pietroforte 1997). Such problems tend to hinder cooperation and learning between actors. Further, problems in the design phase are often seen to cause problems on site, e.g. as poor design quality or lack of constructability (Alarcón and Mardones 1998). This influences the whole project negatively, in terms of increased costs and reduced productivity (Baldwin et al. 1999). Hence, improvement of the design-construction interface can be seen crucial for enhancing total industry efficiency.

Wikforss and Löfgren (2007) stress the need for rapid access to information in both design and construction processes, in order to achieve project success. In building design, this is especially important (and difficult), because it includes several mutually dependent decisions. Moreover, Flager et al. (2009) show that members of the design team spend as much as 58% of their time managing information. With a more efficient information management system, this time can be reduced and used in more value creating activities. Koskela (2000) presented the TFV (Transformation-Flow-Value) concept in construction. As construction processes are reliant on accurate and timely information, it becomes clear how information flow is one that drastically affects all other resource flows by introducing the aspect of flow in building design. Further, the flow view aims to reduce waste in construction processes and thus is especially important to manage from a Lean perspective.

A number of researchers have emphasised effective communication as a means to overcome the problems of the contemporary AEC industry (e.g. Ballard and Koskela 1998; Bowen and Edwards 1996; Dainty et al. 2006; Grey and Hughes 2001). However, despite this being widely acknowledged as one of the main challenges in construction, little progress has been made towards improving communication effectiveness in project teams. Therefore, the research questions addressed in this paper are:

- How does communication take place between design and construction teams?
- What communication challenges exist in the interface between design and construction?
- What can the Norwegian AEC industry learn from communication in the design-construction interface in the German industry and conversely?

A pilot study by the main author showed that poor and missing communication cause many problems in Norwegian industry. A comparative method was chosen to see what, if anything can be learned from Germany, as one of the world's largest construction markets.

RESEARCH METHODOLOGY

The comparative analysis presented in this paper is based on a multiple case-study approach. According to Flyvbjerg (2006), case-study research is a method appropriate for gaining context-dependent knowledge about complex issues. The research includes an extensive literature review, a study of internal documents and semi-structured, in-depth interviews. The literature review focused on communication in building design and was carried out in accordance with the procedures described by Blumberg et al. (2011). Keywords were searched for in research databases (Scopus, Compendex, IGLC Papers and Google Scholar) and library databases. Useful sources were also found in the references of reviewed articles. The review provided a foundation for the identification of general communication success factors and issues. The document study consisted of documents received from respondents, mainly project presentations, schedule plans and organisation maps. These provided details that corroborated information from the interviews (Yin 2014).

A total of 20 interviews in Norway (9) and Germany (11) were conducted, in line with the recommendations of Yin (2014). The Norwegian interviewees represented three different project teams in the same company, and were selected on the basis of experience from previous summer internships. The German cases were chosen in order to gain a better insight into general trends of common industry practice. Therefore, project teams from three different companies were interviewed. By interviewing architects, building design managers, project managers, site managers and foremen, different perspectives were accounted for. The limited sample size of the study does not permit for generalising the results. However, as pointed out by Flyvbjerg (2006), even a small and limited amount of interviews can constitute an influential source of information to generate new knowledge.

THEORETICAL FRAMEWORK

BUILDING DESIGN MANAGEMENT AND COMMUNICATION IN IT

Communication in building design is a wide-ranging area, including formal and controlled exchange of information, just as informal and interactive interaction. Nonetheless, it can be separated into two main groups: synchronous and asynchronous (Emmitt and Gorse 2003). Synchronous communication is direct in-time information flow, by means of verbal channels like meetings and telephone. Conversely, asynchronous communication takes place distant in time and space, through written channels such as e-mails and drawings. Synchronous communication is defined as richer and more effective than asynchronous communication, in accordance with Figure 1. In this context, *richness* refers to the information volume and content complexity a channel successfully can manage. In general, oral channels are richer than written ones, because they also convey non-verbal communication like gestures and tone of voice (Kaufmann and Kaufmann 1998). Effective design teams typically use a balanced mix of synchronous and asynchronous communication (Emmitt and Gorse 2007). Dainty et al. (2006) states that traditional channels such as drawings, meetings and telephone, remain the ones most frequently used in construction. Use of ICT (Information and Communication Technology) tools has, however, increased rapidly in recent years (Wikforss and Löfgren 2007). If implemented the right way, project teams can derive huge benefits from the use of these.

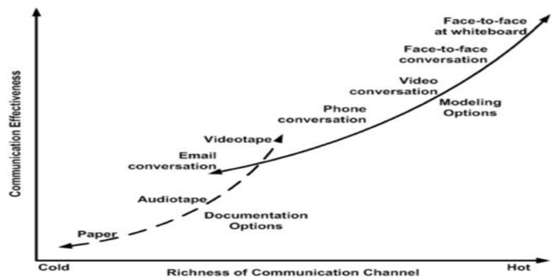

Figure 1: Richness of communication channels (Ambler 2002)

The AEC industry operates in a dynamic and fragmented environment, with temporary project teams made up of ad-hoc combinations of different specialists. Further, the onset of global construction markets leads to challenges related to social and cultural differences. Due to these features, actors interact in a complex environment in which different barriers combine to prevent straightforward information flow (Dainty et al. 2006). At the heart of successful projects lies the design teams' ability to communicate abstract ideas to site and the ability of those on site to translate this into physical artefact (Emmitt and Gorse 2003). Information is required and produced all the way from inception to completion, and many decisions are mutually dependent (Bowen and Edwards 1996). The mutual dependency serves as the glue holding the fragmented organisation together, but also place high demands on the actors' ability to collaborate. As Dainty et al. (2007) point out; building design is dependent on the combined effort of many individuals, their diverse skills and knowledge. Thus, their ability to work together as a team is decisive for the overall industry effectivity. Svalestuen et al. (2015) emphasise the importance of high levels of trust, project commitment and involvement in the goal-setting process as the key factors for successful teamwork. It is therefore essential to strive for these qualities in every project organisation.

Busby (2001) found that errors in actor interaction is the most common failing in building design. In this regard, absence of information and the issue of noise are of huge importance. These matters can impact the clarity of messages relayed between actors, regardless of how suitable and rich the chosen channel are (Dainty et al. 2006). Together, they constitute the major causes of communication failures in construction. Rothwell (2010) defines four types of noise: physical, psychological, physiological and semantic. Physical noise is noise in the literal sense, i.e. sounds from machinery on site. Such noise is hard to control because it is caused by people or the surrounding environment. In contrast, the other types of noise can be controlled. They solely exist in a person's mind and arise in coding and decoding of messages, for example as varying frames of reference.

Reinertsen (1997) argues that facilitating effective communication requires a reduction of current information flow. When too much information simultaneously circulates, it is difficult to separate what is important from what is not. Pietroforte (1997) further claims that an understanding of the organisational structure is essential, as this impacts upon how patterns of communication will develop. In addition, the implementation of modern tools like Last Planner® System (LPS) and Building Information Modelling (BIM) can help to overcome some of the current barriers to effective communication. Research has shown that they contribute to increased process transparency, project commitment and collaboration, which further facilitate streamline information flow (Al Hattab and Hamzeh 2013). Equally, by take into effect building design as a flow of information in accordance with the TFV model (Koskela 2000), time spent waiting for, inspecting, reworking and moving information is minimised. This results in better coordination of interdependent flows and a stronger integration of design and construction. The literature review revealed a gap between current knowledge of team communication and how this is practiced in construction. A lack of qualitative research on this area was also identified. Effective communication is repeatedly regarded as the key to success in AEC projects. It is thus vital to continue to study this field, in order to increase the understanding of the current issues and potentially avoid these in the future.

FINDINGS AND DISCUSSIONS

COMMUNICATION PATTERNS

The analysis of the communication patterns in the German and Norwegian project teams indicated that the choice of project delivery method affects how communication takes place in the organisation. The research revealed that conventional procurement methods like Design-Bid-Build (DBB) are widely used in German industry, while it in Norway is becoming more common with Design-build (DB) contracts. By using DBB, the client is at the centre of the information flow. Unfortunately, clients often lack the experience and skills necessary to effectively manage and coordinate project teams. This may result in an absence of communication between design and construction. In contrast, the DB method organisationally integrates the design and construction processes. Additionally, with DB, the Building Design Manager becomes accountable for managing existing interfaces. Both German and Norwegian practitioners expressed that this was a huge advantage, as the design managers are more likely to be in possession of the appropriate qualifications.

In the German organisations, it was observed a more palpable organisational hierarchy in comparison to what was seen in Norway. German actors also seemed to have a great respect for roles and responsibilities as defined in the Responsibility Assignment Matrix (RAM), leading to an inherent confidence about their own and other actors' role in the team. Contrastingly, in Norway the informants described an unstructured situation with actors often feeling unsure about their place in the organisation. Additionally, the responsibilities in the execution phase often differed from what was defined in early-phase. This raises question as to whether the RAM has been clearly communicated to participants or simply been forgotten.

In both countries, face-to-face contact was defined as the most common communication channel and essential for project success. By enabling immediate feedback and transfer of rich information, it makes it easier to detect and avoid misinterpretations and ambiguities. In addition, the channel was defined as important for reducing organisational fragmentation, as it helps to strengthen the relationship between the different actors, disciplines and phases involved. The research further revealed that use of e-mail, telephone and tablets is common in both Norway and Germany. ICT tools like project intranets and BIM are commonly used by Norwegian actors, but rare in the German industry. Moreover, the findings implied that ICT tools used in both countries (e.g. applications for registering errors and deficiencies) are better developed and integrated Norway. The respondents described many of the same reasons for one team member to contact another, including to plan, coordinate and schedule work, to give/receive information, to give/receive information because of changes and to request late/missing information. In both countries, respondents wished to communicate more with the purpose of sharing knowledge and to determine level of ambition (e.g. cost, time and quality level). This indicates that important teamwork principles, such as definition of a common goal and application of positive and negative sanctions, often are overlooked or underestimated in AEC projects. These are important value creating activities, contributing to a successful final product. Therefore, when they are not prioritised, the probability of rework, delays, cost overruns, etc. will increase, further affecting the overall performance of the project team.

COMMUNICATION CHALLENGES

A common perception among practitioners in both countries is that most project teams underrate the need for communication. Additionally, the pre-construction time is typically found to be too short. The majority of the practitioners had experienced a need for more extensive communication and planning than what was originally scheduled. When enough time for up-front planning is not allocated, the frequency of conflicts regarding time, cost and quality requirements increases. Further, the pre-construction stage is a good arena for project participants to get to know each other and identify each other's strengths and weaknesses. Both German and Norwegian practitioners underlined the importance of good interpersonal relations and trust. Even more than in other industries, human factors seem to determine whether construction projects develop in a good way or not. The respondents maintained that when there is a good "chemistry" in the project team, project dedication and collaboration are strong, and planning, coordination and information flow usually run smooth. Unfortunately, as a consequence of the industry's project based and fragmented environment, these properties are often difficult to establish.

Several challenges related to the use of e-mail were described, in spite of its important role when sharing project information. Firstly, there are often too many recipients, resulting in an information overload and actors overlooking information. Secondly, as a consequence of their low information richness, long e-mails with complex information are often misunderstood. The respondents also explained that e-mails often result in project information becoming disorganised and information getting lost. This issue concerns how actors can provide the right information to the right team member at the right time, rather than opposing the different communication channels. Hence, a pre-set framework describing where and when to use the available communication channels is important to ensure a smooth flow of information throughout the project.

The analysis of the German industry indicated that many communication challenges arise as a result of the procurement method they use. The DBB method allows for many actors taking part in decision-making, and thus leads to an increased complexity. Project participants also expressed that cooperation problems often occur between the client, contractor and architect, for example as a result of competing interests or different jargons. This shows once again the importance of establishing a common set of team rules. German actors also explained that they have a great pride in their work, which sometimes make them incapable of receiving help from others. Many of the challenges described in Norway are considered a result of organisational culture, e.g. unclear roles and responsibility, lack of initiative and motivation and too much informal communication. These issues result in a confusing information flow, giving rise to uncertainty and decreased productivity. The findings also indicate that the vast focus on organisational decentralisation in Norwegian industry during the last few decades has come at the expense of an organisational structure with clear roles and responsibilities. Unfortunately, effective communication seems difficult (maybe even impossible) to establish and maintain without a distinct system.

LEARNING BETWEEN NORWAY AND GERMANY

From the study of the Norwegian and German AEC industries, several initiatives to facilitate effective communication in the design-construction interface emerged. Among others, Norwegian project teams had implemented parts of the LPS, which had increased project commitment and feeling of responsibility for the final product. Moreover, the use of ICT tools has evolved rapidly in Norway in recent years. Project intranets provide all team members immediate access to project information, thus speeding up information flow. Video conferences makes it easier to communicate with other participants, even over long distances. Yet, it was implied that the use of these tools can be troublesome and also reduce the overall understanding of the project. For example, when all participants have access to all information at any time, it is hard to control who receives what and when. In worst case, this can result in actors making their own "image" of the project, which however might not always correspond to the overall project objectives.

The comparative analysis indicated that Norwegian and German actors have different views on how organisations should be structured in order to best facilitate for effective communication. In Norway, it is a strong focus on the flat organisational structure. Advantages of this approach include open and more effective communication, decision-making and collaboration. On the other hand, a flat structure may foster role confusion and thus hinder employee's motivation. As opposed to the Norwegian actors, German actors emphasised the importance of maintaining a certain degree of organisational hierarchy. The research showed that this approach results in clearer reporting lines and chains of command, which further ensure clear division of roles. Moreover, German actors stressed the importance of project participants being motivated and well prepared for the work. This was defined as easier to achieve when all actors have a clear picture of their responsibilities. However, there are disadvantages of using relatively rigid hierarchical structures, such as less effective decision-making and communication flow, which arise as a result of increased bureaucracy. Further, hierarchical organisations are known for being slow to react upon new opportunities, which makes it hard to survive in today's rapidly changing environment. This may help to explain why German industry seems to be slower to adopt new technology and work methods.

One respondent who had worked several years in both the German and the Norwegian AEC industry made an interesting point. He claimed that the right balance between a hierarchal and a flat approach is necessary to create effective communication in the design-construction interface. The case studies implied that one of the German companies had achieved exactly this. By basing their work on standardisation, pre-fabrication and the supply of a total design-build service they had succeeded in safeguarding a distinct structure, while at the same time allowing for an increased involvement in decision-making, as well as the adaption and development of new work methods and technologies. The interviews clearly indicated that this increased the effectivity of communication in the organisation, which in turn led to an improved performance. However, it is important to point out that not all organisations have the opportunity to structure their practice this way.

CONCLUSIONS

The German AEC industry is generally characterised by the use of traditional work methods, reflected in the prevalence of conventional procurement methods and the limited use of ICT tools. The communication patterns developing in the project team are clearly influenced by the use of traditional methods, among others there was seen a lack of communication between design and construction teams in German project teams. On the other hand, the Norwegian industry looks for constant development, illustrated by their extensive use of modern tools like the LPS, project intranets and BIM. From a communicative perspective, this helps project teams to increase their efficiency

Table 1: Challenges of Communication in Germany and Norway

Both countries	Germany	Norway
Underrated communication need	Client "in charge"	Unclear roles and responsibility
Short pre-construction	Competing interests	Need to request information
Information overload	Different jargons	Lack of motivation and initiative
Unstructured information	Averse to receive help	Much informal communication
Interpersonal relations and trust		

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At the same time, the comparative analysis showed that there is a need for improvement of communication in Norway, just as it is in Germany. Table 1 depicts the identified communication challenges identified in this study.

The German and the Norwegian AEC industry represent different views on how to best facilitate for effective communication. In Germany, a hierarchical approach is typically used, while a network-like structure is most common in Norway. The study implied that a flat structure has several benefits. It can, however, result in a chaotic project environment because of too much independency and a weak structure. The hierarchical approach, on the other hand, typically maintains the structure, but decreases the effectivity of information flow and prevents the organisation from developing. Thus, when alone, none of these methods are capable of improving the current situation. However, in exploring theory and practice, it has been found that from a communicative perspective there is no *either-or*, but rather a *both* on this matter. By balancing the Norwegian and German approaches, companies can benefit from the current strengths of both countries as presented in Table 2. In combination, these two approaches to effective communication can help to solve some of the challenges of contemporary AEC industry, which became further apparent from the research done German industry. These findings revealed that companies exist that have achieved to maintain a distinct structure, while also keeping pace with the industry's continual development. However, this structure is not feasible for most firms because of the way it limits the range of projects, while also requiring a certain organisation size.

Table 2: Strengths of the German and Norwegian approach

Germany	Norway
Clear communication paths	Allows for innovation
Clear chains of command	Simpler and faster decision-making processes
Clearly defined set of responsibilities	Independent employees
Motivated and committed employees	Improved speed of communication flow

Based on the findings from this research, it seems that the methods and technology needed to improve communication between design and construction teams already exists. The question of how these solutions best are combined and implemented, so as to avoid the present negative impacts on the industry, still remains. According to the research presented here, the answer lies in finding the right balance of a hierarchical and a flat structure, the formal and the informal, use of technology and not, and so on. Future research should be dedicated to the development of a strategy for how to best accomplish this in practice. The authors do recommend, however, that project teams have a hierarchical structure in terms of decision-making, which will make the flow of information more structured and easier to control. At the same time, it is important to be critical to adopt new methods and technologies if the advantages that these entail for the project team is not clear. As can be learnt from Norwegian industry, an uncritical implementation of such tools can – in the worst case – reduce the overall performance of project teams.

Summing up, this study has shown that improvement of communication and information exchange in building design management increases the overall effectivity of the construction industry. Further, such an improvement may involve changes in project organisations and work activities. The research is based on a limited number of respondents. This may not make the results 100% applicable to all projects. Hence, in the future, the authors recommend to extend the numbers of respondents. In addition, more research should be done on the relationship between Project Delivery Method and communication.

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EVIDENCE-BASED DESIGN IN HEALTHCARE: A LEAN PERSPECTIVE WITH AN EMPHASIS ON VALUE GENERATION

Y. Zhang[1], P. Tzortzopoulos [2], and M. Kagioglou [3]

ABSTRACT

Evidence-based design (EBD) has been discussed in the literature, including its potential benefits and its limitations for its isolated and fragmented knowledge application. This study is an attempt to integrate the currently fragmented EBD findings to guide decisions for better designing, building and adapting hospitals through Lean thinking with an emphasis on value generation. An EBD review and assessment was carried out to update the current developments in the field. The paper discusses the importance of applying EBD in an integrated way. This is achieved through the development of a conceptual holistic framework based on three data strands inspired through Lean thinking, namely: Building performance, life-cycle cost and user value related evidence. This is an initial attempt and the paper concludes by identifying the limitations and potential future studies.

KEYWORDS

evidence-based design, healthcare, Lean, value,

INTRODUCTION

Healthcare building design presents a complex architectural challenge. Interest in EBD has been growing extensively since Ulrich's 1984 publication addressing the effect of views of nature on patients (Marcus and Barnes, 1999, Ulrich et al. 2008), and proper design decisions at initial stage will not only maximise the occupants' health benefit (Huisman et al. 2012), but also improve the service delivery (Grazier, 1999) and reduce life-cycle costs (Harris and Fitzgerald, 2015).

The idea of lean principles is to make the production process more efficient by reducing any sort of waste in the process, which has become also important for general management, and other disciplines like product development and construction. In healthcare, Lean has been targeted at problems that undermine the delivery of effective healthcare services. The

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concept of lean design has been also studied with a specific focus on the design of healthcare facilities for better value generation (Tzortzopoulos et al., 2005).

There is a clear link between the concept of EBD and that of value generation from a lean design perspective. However, our understanding of EBD and its application is still limited as there is scarce research in the area. This study is an attempt to integrate the currently fragmented EBD findings to guide decisions for better healthcare design through Lean thinking. In brief, the following questions are explored:

- How to fuse diverse information from different sources to generate actionable design information?
- How to ensure applicability of the results (use of information by designers)?

In order to answer these research questions, the paper is structured as follows: It begins by presenting an EBD review and assessing the current state of development of the field. Following, issues on the area of EBD are discussed. The paper goes on to present a conceptual framework based on the literature review and concludes by identifying limitations and potential future studies in this area.

THE CONCEPT OF EVIDENCE-BASED DESIGN

What is the concept of EBD? how it has been tackled by research? and how it may fit into the design process? These will be presented using examples drawn from diverse studies.

The earliest known meaning for the word evidence date from the 1300's and refers to 'appearance from which inferences may be drawn'. Other meanings from later periods also exist and refer to 'proof, distinction, clearness, ground for belief, obviousness' (Harper, 2011). Kelly (2008) pointed out that 'evidence' is directly related to knowledge reliability, which depends on the rigour of evidence gathering and authenticity of the relationship between evidence and phenomena.

This argument has been expanded further in the healthcare disciplines in many ways (Gray, 1997). The initial attempt to use the evidence as a supporting approach in decision making happened in the field of medicine, with a focus on identifying the best treatment alternative for patients based on individual clinical expertise with the best available external clinical evidence from systematic research (Sackett et al., 1996), which became known as evidence-based medicine (EBM). So far this concept has been used in other areas including the care of an individual (Lu et al, 2014), an organization (American Dental Association, 2013) or at the policy level (Boden and Epstein 2006). The success of this approach led, in the 1980's, to the start of discussions related to the adaptation to the field of design, giving origin to evidence-based design. Inspired by EBM, a few definitions of EBD have been proposed:

- Design solutions for healthcare buildings to create environments that are therapeutic, supportive of family involvement, efficient for staff performance, and restorative for workers under stress (Hamilton, 2003).
- A process for the conscientious, explicit, and judicious use of current best evidence from research and practice in making critical decisions, together with an informed client, about the design of each individual and unique project (Hamilton and Watkins, 2009, derived from Sackett et al. (1996))

- It is a process involving the reorganisation of thinking, the in-depth investigation and gathering of research, the development of scientific questions and hypotheses and, ultimately, the testing of creative and innovative design solutions (Cama, 2009).

According to Fischl (2006) this approach aims to provide scientific evidence to fill the designer's knowledge gap about humans' social and behavioural attitudes towards the surrounding environment. In this respect, the researcher/designer works as an interpreter investigating and describing human behaviour, wants and needs, which implies in changing the traditional practice of architecture once designers are increasingly required to have considerable knowledge beyond their own field (Hamilton and Watkins, 2009).

CURRENT RESEARCH ON EVIDENCE-BASED DESIGN

There are quite a few literature reviews on EBD published in recent years. Some focus on collecting the evidence in healing environment that can make a difference to the patients' health conditions (Salonen et al. 2013, Huisman et al. 2012). Broadly speaking, studies have been focusing on the therapeutic effects of design from three main perspectives: physiological proof, psychological studies and design theory (Codinhoto et al., 2009). These reviews were very informative in terms of updating the state-of-art evidence including both quantitative and qualitative studies.

As the assessment of evidence heavily rely on its reliability (Kelly, 2008), randomized controlled trial (RCT) were considered rigorous studies with credible data and commonly viewed as providing the highest level of evidence (Evans 2003). The findings from RCT has important implications for those developing practice guidelines and recommendations mainly because the processes used during the conduct of a RCT minimize the risk of confounding factors influencing the results (e.g. Walch et al., 2005). Recently there is a debate that the RCT is not an appropriate methodology in research on long-term healthcare settings, in part because of "*the virtual impossibility of randomly assigning individuals to different environmental / treatment interventions and controlling cross-site variations*." (Calkins 2009, pp146). However, there is an increasing evidence of how environmental cues link to physiological functions in the human body and therefore therapeutic outcomes (Sternberg, 2009).

The studies carried out without random assignments are called quasi-experiments, which follows same RCT methods. A common form is comparative studies with a discussion that the difference of group baseline was compared and then adjusted in data analyses. The research normally collected data from two different built environments and analysed them using same measuring tool, e.g. predefined activity task, comfort / satisfaction level and energy cost annually etc. (e.g. Beauchemin and Hays, 1996). Another typical example is a comparison between before-and-after scenarios. Two sets of data were collected from same group of occupants before and after moving into a new building, a refurbished environment, or any facility replacement (e.g. Tyson et al., 2002). Comparative studies can produce a rich source of information and give a certain confidence to embark on the new design strategy intervention. However, it is difficult to extend the results and findings to other building cases due to its small sampling size. Only when obtaining more evidence in a similar way can actually identify and eliminate alternative explanations.

Post-occupancy evaluation (POE) is a typical quantitative study type without seeking causation but evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time (Preiser et al., 1988, Sherman et al., 2003). Nowadays, POE is one of the most popular way in terms of collecting evidence from varied functional building types, office, schools and hospitals. Unfortunately, these works are mainly supported within academic institutions and tend to be specific to research purposes rather than being routinely applied to mainstream building design practice, e.g. feeding it forward to new projects.

Besides the quantitate studies discussed above, qualitative studies, e.g. interviews, focus group, workshop, site observation, etc. are some common methods especially to those studies that interest in problem solving, innovation (new study area), complex opinions, beliefs and attitudes (e.g. Rowlands and Noble, 2008). The qualitative studies are very project (case) focused and do not provide a strong evidence base for practice. However, it provides potential design interventions and opportunities for future studies that require additional investigation and evaluation (Evans 2003).

This section summarized the current research in EBD. What is shown is that evidence collected for healthcare buildings come from multi-dimensional perspectives and through varying methods, depending on the study interests and targets. Though research and studies made an effort to contributing the richness of the data, yet there are questions regarding the evidence integration for the most effective design solutions and actionable advice for future healthcare building projects. Therefore, a holistic approach is needed.

METHOD

Literature review is used with an emphasize on two aspects which responds to the research questions that set out in the 'Introduction':

(1) *Maximize value (Optimise the healing environment)*: There is an illustration of EBD refined by Lima (2014) called the three-legged stool which was from Spring (2007) originally (Figure 1) captured the essence of an individual's holistic experience of design decision-making process. Her work becomes a starting point for this study and literature review were carried out to establish the links between design decision-making (EBD means) and value generation (Lean output). (2) *Development of a theoretical framework:* Recently, some researchers have explored the potential solutions to create a manageable framework that integrate varied design features together. For example, Durmisevic and Ciftcioglu (2010) developed a framework through a fuzzy neural tree structure that combine the EBD for more efficient use. Rybkowski and Ballard (2008) use the 'five whys' as a decision-making framework for EBD to ensure that multiple options are considered before final solutions are adopted. Inspired by their work, the conceptualization of three Lean strands becomes the base for the literature review to develop the framework specifically fit into healthcare building design for value generation.

CHALLENGES FOR AN INTEGRATED APPROACH

Lean is associated with the elimination of waste (Womack and Jones 1996) and value generation (Hines et al, 2004). Today, the emphasis on 'value' and how it can be generated and maximised, is growing rapidly. The value generation process was argued through many viewpoints. One of the essential issues regarding value is how to define and measure it (Koskela, 2000). According to Zeithaml (1988), perceived value is the consumer's overall assessment of the utility of a product based on perceptions of what is received and what is given. To provide benefits, a product or service must be able to perform certain tasks or functions, solve identified problems, or provide specific pleasures (Monroe (2012). Haque and James-Moore (2004) also argued that engineers need to move from a production focus in which the primary aim is waste reduction to one of identifying and enhancing value. Clearly, there appears to be a significant opportunity to benefit from the adoption of Lean in EBD for healthcare design, as the key concepts are similar: it tries to identify the effective and efficient design solutions for value generation. Inspired by previous works (Spring 2007, Lima 2014), Figure 1 maps a link between lean and EBD.

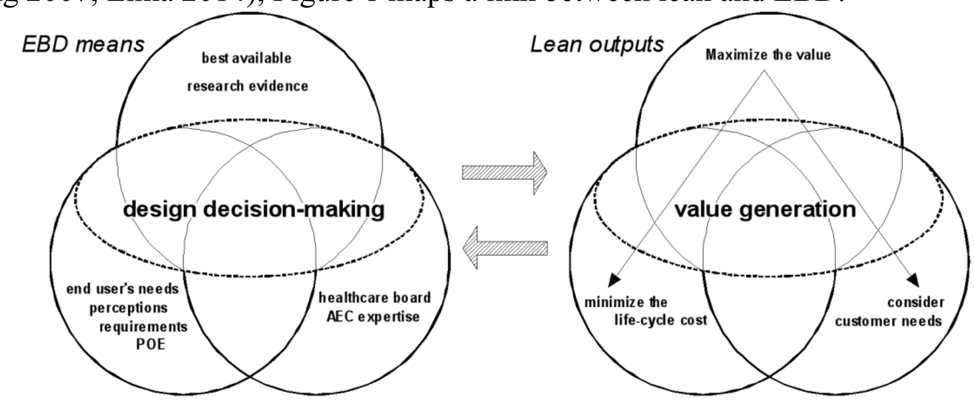

Figure 1: Links between Lean and Evidence-based

MAXIMIZE VALUE (OPTIMISE THE HEALING ENVIRONMENT)

Baines et al. (2006) carried out a systematic review and stated that an understanding and definition of value is key to success when applying the Lean. Gautam and Singh (2008) in their lean product development study argued that when existing product design is modified to improve its perceived value, it is important to identify and pursue those changes (decisions), which give maximum improvement in the perceived value. Healthcare buildings are purpose-built for a specific functioning usage: healing. Crucially, it supports not only the functional but also emotional needs of all healthcare facility users (patients, staff, visitors). In this context, value can be tangible (such as staff absenteeism, medical errors, falls, budget plan, service cost, energy consumption etc.) or intangible (such as comfort, satisfaction, quality of sleep and working efficiency etc.). Patients, staff, visitors are particularly affected by the intangible aspects of the building.

Most studies tended to follow a similar perspective, developing one specific evidence to address specific health outcomes. EBD needs to endeavour to combine all individual design features that lead to positive impact to optimize the healing environment, and designers could use these evidence to make decisions based on the best information available. However, the evidence fragmentation makes it difficult for implementation in practice because the value is unpredictable due to the different level of credibility. Therefore, the implementation of EBD confronts a big challenge due to lack of the integrated evidence. Lean is a holistic approach, which can be interpreted as 'emphasizing the importance of the whole and the interdependence of its parts.' In this case, two central arguments were explored in terms of the evidence integrating.

Minimize the life-cycle cost (guide the investment decision)

Minimizing the life-cycle cost is one of central arguments when it comes to maximizing the value generation. Life-cycle costs, in AEC industry often refers to the initial cost with future-based costs like running, operation, maintenance and replacement etc. (Bennett, 2003). Despite the benefits of EBD, there are economic barriers to implementing EBD in healthcare projects. Central to the business case is the need to balance one-time construction costs against ongoing operating savings and revenue enhancements (Sadler et al. 2008). According to several sources 70-90 % of the total life cycle costs become defined already in the design phase and once the design is completed, the potential to reduce the cost in later stages is rather small (Bescherer, 2005). However, the implementation of lean in design has been slow, exactly at the stages where decisions have a major influence on the level of value realised in the project (Emmitt et al. 2004).

Nowadays, healthcare worldwide is facing severe funding constraints and increased pressures on the quality of healthcare delivery, which means the updated knowledge that could guide investment decisions during the initial phases of healthcare projects becomes more crucial. Blair et al. (2011) proposed an updated hypothetical Fable Hospital 2.0. The cost premium for 16 separate EBD interventions, e.g. single patient rooms, sound absorbing ceiling tiles and larger windows etc. was estimated to be 7.2% on a $350 million hospital build. As described by the authors, the payback for the Fable 2.0 investment should occur within three years—a reasonable return by any business standard.

Consider the customer's need (focus on user-centred design of the healthcare)

A critical point in lean thinking is to consider the customer' needs, enhancing the value to them by adding product or service features and/or removing wasteful activities. Mikulina (1998) states that each of the participants on the new product introduction process should work only when and on what is needed, or in other words 'in demand by customer'. Paralleled with customer-driven idea, user-centred design also emphasised that the integration of knowledge of users work practice, preferences etc. into the design process is crucial to a successful design outcome (Norman and Draper 1986).

To build a user-centred environment is particularly crucial for healthcare facilities, where occupants are likely to experience a psychologically difficult situation. Recent developments in healthcare design have highlighted the importance of 'humanizing' healthcare contexts by focusing on a set of design attributes, which should be provided in order to satisfy fundamental users' needs (Evans and McCoy, 1998), e.g. privacy and social interaction; perceptual consistency; control over space. In a situation of increased sensitivity, to create a relaxing environment, pictures on the wall, soft background music and beautiful view outside have potential to reduce anxiety and depression of the patients and staff (Ulrich et al. 2008).

From the discussion above, it was found that Lean thinking has the potential in integrating the EBD knowledge particularly in enhancing the building performance, lowering the life-cycle cost and the patient-centred benefits.

DEVELOPING A HOLISTIC FRAMEWORK

Though compelling arguments were made on the importance of EBD, few well-constructed empirical studies have been carried out to explore the complexity and interactions of the healing environment as a whole. Within this challenging context, one potential research focus is to take an integrated approach to identify the impacts of the built environment on health outcomes. Lean concepts provide a conceptual basis for this.

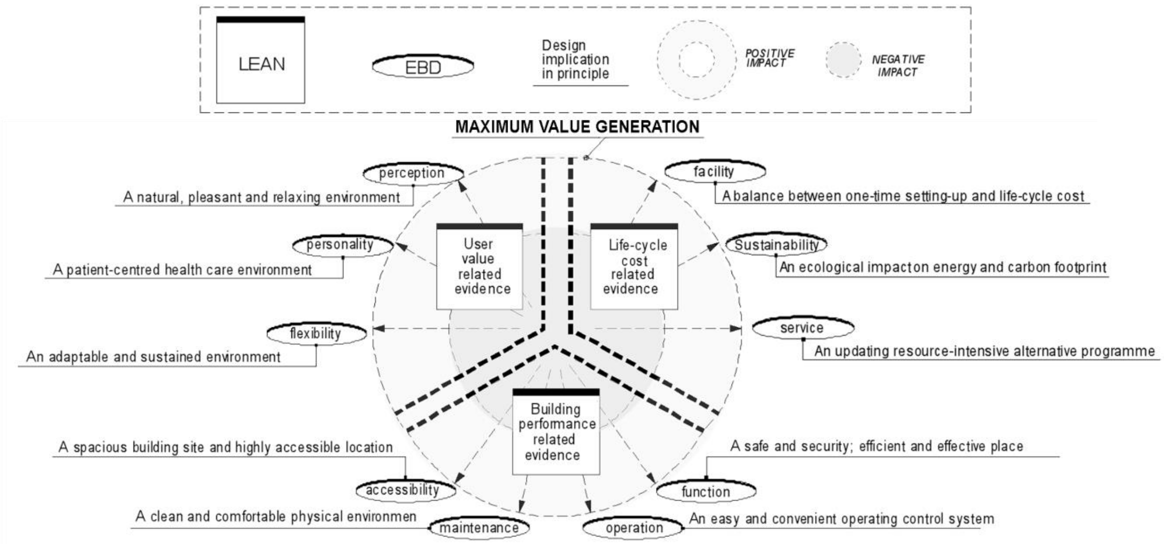

Figure 2: A conceptual framework for implementation of EBD integration and examples of evidence in each data strand

Figure 2 is an initial attempt to fuse diverse information from different sources to generate actionable design information. Based on available literature, some of which has been presented in this paper, it maps a holistic view of the EBD implementation through Lean in terms of value generation. Some design implications in principle in each strand are also given to ensure applicability of the results (use of information by designers). There are three data strands and each one represents one perspective of decision making that needs to be considered and integrated to determine the value generation to the customers. *Building performance related evidence* plays an essential role in providing a well-functioning healing space. *User valued related evidence* will optimize the healing environment from patients, staff and visitors' point view. And the *life-cycle cost related evidence* will guide the investment decision in order to ensure the the best available resources for value generation. It has to be mentioned that the EBD included in each Lean strands are not identified in an isolated way. For example, the maintenance focus on providing a clean and comfortable environment (building performance related evidence) which will directly affect the user perception (user value related evidence). Their positive/negative feedbacks may further become a solid evidence in updating the healthcare service (life-cycle cost related evidence). In this case, which Lean strands the evidence is located does not matter. What matters for this holistic approach is that these EBD characteristics are included in this framework to be taken into consideration.

LIMITATIONS AND CONCLUSION

The ultimate goal of EBD is to generate actionable advice that could be used as the basis for healthcare building design and improvement (including refurbishment). However, due to the fact that (i) the evidence is scattered and heterogeneous, (ii) the effect on end-users' health and wellbeing is at varied levels and perspectives, naturally, it raised a very popular question: what is the best design solution? Or what evidence can inform the designer to locate the main resources to the most effective design solutions? Though compelling arguments were made on the evidence and their impact, very few well-constructed empirical studies have been carried out to explore the complexity and interaction of the healing environment as a whole. The paper discussed the implementing EBD in healthcare building design at early stage through Lean thinking.

It has to be mentioned that this paper does not attempt to collect and review all EBD in healthcare; nor does it provide a final framework for the practical usage. The particular objective is to focus on the current EBD knowledge in an integrated way based on value generation. It presents the starting point of our research in this area with unavoidable limitations. For example, it is constrained by the lack of clear demarcation point between evidence and other factors influencing the value generation and maximization (e.g. wellbeing when compared to the effects of the physical environment.) By discussing and publishing, the research team aims to continually improve the integrated approach, being open to new ideas and constructive suggestions. This paper is part of this process, an exercise in critical reflection and appraisal. Hopefully, a future developed framework will provide the means by which better understanding and actionable knowledge can be generated for healthcare building design. And the integrated approach through Lean thinking will be a promsing area for healthcare buildings' research, highlighting the importance of the design challenge for policy makers, designers and users.

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CRITICAL REVIEW OF TOLERANCE MANAGEMENT IN CONSTRUCTION

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ABSTRACT

The current practice of Tolerance Management (TM) is still very ad hoc and reactive, despite increasing calls for waste reduction and an improved quality of buildings particularly within industrialised construction. This paper aims to identify the root causes of tolerance problems, the reasons why current methods have not been as successful as expected and why the industry still struggles with this issue. Having reviewed and interpreted the existing literature, it is apparent that tolerance problems fall into two categories defined by intrinsic and extrinsic factors. Furthermore, the drawbacks of the existing methods for TM were analysed, and the findings show that none of the existing methods have been considered in a continuous and holistic process and they remain scattered.

KEYWORDS

Tolerance Management, Root Cause Analysis, Industrialisation, Integrated Design and Construction

INTRODUCTION

Following the precedents set by Plato and Aristotle on the study of Geometry, Hugh of Saint Victor was the first medieval scholar who divided this subject into practical skills and theoretical skills, sometime between c.1125-1141. He applied geometrical theories in practical ways and interpreted several structures. This achievement in design specification made it possible to design buildings more accurately, facilitating the setting out the building and checking the finished parts and their relative dispositions (Addis 2007). Since then, there has been a continuous progression in using specifications to generate building designs.

The use of design specifications in manufacturing, including tolerances, has evolved to support design inter-changeability and mass production. Tolerances have a key role in the

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assembly and production process, because parts that are made independently are expected to function coherently with adjoining parts (Creveling 1997). Holbek and Anderson (1977) state that although tolerance specifications in the construction industry have been developed for materials such as steel and concrete, there is little input on the issue of conflicting tolerances at the interfaces between different materials and components. Almost 40 years later, the industry still struggles with the same challenges and the subject of interfacing between components is yet to be resolved.

Designers often do not consider the constructability of their design in terms of tolerance (Alshawi and Underwood 1996) or accommodate this adequately into the design process (Milberg 2006). As a result, contractors often misunderstand the designers' intentions and solutions (Alshawi and Underwood 1996). Moreover, addressing tolerances on site still relies layman knowledge, like the early days of the manufacturing industry (Milberg and Tommelein 2003).

There are many books and published papers in construction that consider tolerance as a minor topic. Few of them extol any improved TM, particularly for its ability to minimise defects. (e.g. Feld and Carper 1997; Sacks et al. 2010). Whilst there are few novel research contributions to this field (e.g. Milberg 2006) there is no evidence to indicate that they are widely used in the industry. The reason might be that they are expressed in a difficult format for the industry to understand, interpret and apply. According to Forsythe (2006), much of the literature on tolerances is based on the participants' perspective rather than empirical data. The existing methods used for TM in construction have been adopted from manufacturing, sometimes even without refinement towards a more relevant application. They lack a holistic and continuous process, even though the improvement of TM needs the development of a method which (1) emphasises the continuous process of improvement and learning from experience and (2) must be holistic which means it must start from the design and continue to the implementation procedures (Seymour et al. 1997). In other words, they are very scattered. Moreover, the use of recommended solutions are often either time consuming (e.g. geometric and dimensional tolerancing) or expensive (e.g. requiring a higher level of inspection) given the current level of technological development in the industry. In fact, there is no single methodology for TM that defines a practical step-by-step approach to developing optimal tolerances from product development to project handover, while balancing the cost for any given design. As a result, TM in the construction industry still remains very ad hoc.

Lean construction concept has been successful in improving building quality and reducing waste. However, TM has not been directly addressed by this concept. In despite Koskela (1992) and Koskela (2000) are amongst the first researches, if not the first, to warn the industry of tolerance problems and highlight the need to address TM, the focus on TM is still missing and tolerance problems seem to be accepted in the industry. Milberg and Tommelein (2003) concur that this is due to a lack of awareness of the cause and effect of tolerance problems, and that the current knowledge of tolerancing is tacit. This paper, serving as an initial output of a PhD research, aims to (1) critically discuss the root causes and consequences of tolerance problems and (2) analyse the two solutions that are considered to be effective for the improvement of TM, namely industrialisation and integrated design and construction. The paper is based on reviewing and interpreting existing literature. It is envisaged that the findings will be developed further using empirical data.

TOLERANCE MANAGEMENT IN CONSTRUCTION

All materials and elements in the construction industry have their own dimensions and their position is specified on drawings. In reality however, elements and materials cannot be exactly level, plumb, straight, and positioned as they were designed. "*The accepted amount of this variation is the tolerance of the material or installed position of the material*" (Ballast 2007). The construction industry primarily requires an understanding of new terminologies related to tolerances: TM, tolerance problem, tolerance failure, and tolerance incompatibility are the terms that must first be explained. According to Milberg (2006), TM is about utilising various tools and methods in order to (1) attain the highest conceivable quality and performance to deliver the maximum value and (2) to avoid any interruption of flow due to tolerance-related problems to minimise the waste.

Regarding *tolerance failure*, the term failure itself is often defined as a human action that exceeds some limit of acceptability. Feld and Carper (1997) speculate that failures result in catastrophic consequences when there is nonconformity with design expectations. An example of failure is structural collapse that is often followed by dispute and litigation. Tolerance failure can thus be defined as an unacceptable deviation from specified tolerances that result in catastrophic consequences and require costly and time consuming re-work. *Tolerance problems* can be perceived as performance problems that are less catastrophic and can be remedied without laborious rework. The term tolerance problem should be used as long as the accentuation is not on deviations that dramatically damage structural integrity or performance capability. According to the American Concrete Institute (ACI) Committee (1990), *tolerance incompatibility* refers to the interface of two materials with different levels of dimensional accuracy. An example of tolerance incompatibility includes the interface between metal curtain walls or partition walls with structural frames.

The construction industry is unique in that tolerances range from thousands of an inch for many manufactured items to several inches for many field installed components (Ballast 2007). This is because the construction industry is currently in a difficult transitional state, between being either craft-based or industrialised (Koskela 1992; Douglas and Ransom 2007). Some elements and materials that are produced off-site such as glass, timber, and steel have a high level of dimensional accuracy while it is difficult to reach precision in other components such as in-situ concrete elements (Koskela 2000). In order to achieve a tight fit between these two types of components, the industry often relies on received tradition (Milberg and Tommelein 2003) using filler materials (e.g. mastic, foam, cork) and grinder.

Even though tolerance problems can be proactively eliminated in the design stage, they are predominantly identified during the inspections and corrected in a reactive manner. Responding to tolerance issues in a proactive rather than reactive manner requires (1) the identification and elimination of the root causes (Meiling et al. 2014) and (2) an understanding of the severity of the consequences of the tolerance problem, in order to take appropriate preventive actions. These two factors are intrinsic parts of a continuous improvement process.

ROOT CAUSES OF TOLERANCE PROBLEMS

Current literature identifies few categories of the root causes of tolerance problems. For example, Seymour et al. (1997) argue that tolerance problems should not be seen as root causes of sporadic defects, but chronic defects. They speculate that current conventions are not effective for tolerance management. Milberg (2006) divides the root causes of tolerance failures by analysing case studies into the following six tolerance failure modes: multiple interpretations of tolerance specifications; incomplete or missing tolerance specifications; standard process capability & tolerance specification mismatch; poor workmanship/below standard process capability; functional, fabrication, construction & inspection tolerance specification mismatch; and inconsistent tolerance loop. Jingmond and Ågren (2015) believe that tolerance problems are due to both exogenous factors (manufacturing tolerances) and endogenous factors (positioning tolerances).

Having reviewed and interpreted the existing literature, it can be concluded that tolerance problems are the result of a complex interplay of extrinsic and intrinsic factors. Intrinsic factors are more related to processual causes, while extrinsic factors are more related to technical causes. This categorisation shown in Tables 1 and 2 give a concise view of the root causes of tolerance failures in the industry, encompassing all former categorisations. However, the list is not exhaustive and needs to be developed based on more empirical data.

CONSEQUENCES OF TOLERANCE PROBLEMS

The consequences of tolerance problems result in two key aspects: (1) incurred defects and chains of waste, and (2) an unsatisfactory performance of the building.

Defects and chains of waste: Tolerance problems are considered as one of the root causes of defects both in manufacturing (e.g. Henzold 2006) and construction (e.g. Seymour et al. 1997; Jingmond and Ågren 2015). Defects result in rework which in turn often cause more errors incurred by operatives, variation in project scope or quality, time and cost overrun, and dissipation of human resources (Love et al. 2009). According to Koskela et al. (2013), the effects of waste remains in a process and causes further waste. When investigating one specific waste, it must not be considered singularly, but rather as a "*chain of waste*" that can be caused. Hence, tolerance problems not only cause defects but also create chains of waste. For example, such problems in structures may affect structural integrity, as well as operating capability or abutting components (Milberg and Tommelein 2003). Tolerance problems and the following chains of waste have indirect and adverse cost impacts due to the deterioration in quality of related activities, longer project lead time (Milberg 2006), and incompatibility of tolerances in the end product with standards and contractual agreements (Forsythe 2006). They also have direct impacts as a result of the cost of the rework (Milberg 2006). Moreover, tolerance problems impact the customer satisfaction and are often at the centre of disputes between the consumer, contractor, supply chain, and Client (Forsythe 2006).

Table 1: Root causes of tolerance problems

Factors	Description
Lack of standardisation	Standardisation is essential to establish 'lingua franca' to enable co-operation between different actors involved in a project (Star and Griesemer 1989). Design teams are often unaware of the circumstances and working systems on site due to a lack of co-operation followed by a lack of standardisation. This shortcoming often results in sloppy designs with tolerances that are either overly restrictive or lenient. Documentation is one of the most important aspects of standardisation. The industry has difficulties in capturing, storing, sharing and re-using all the information and knowledge relating to and arising from a construction project, assuming that it exists, but much of it is never produced (Shelbourn et al. 2006). Indeed, there is no widely accepted systematic documentation mechanism to encourage control and review process, propagate new knowledge, and share best practices (Roy et al. 2005) in order to convert the tacit knowledge of TM into explicit knowledge and avoid repeating the same mistakes in design and on site. Documentation can eventually lead to establishing a repository which foreshadows both extrinsic and intrinsic causes of tolerance problems.
Poor workmanship	Poor workmanship is a typical source of tolerance problems and refers to performing tasks that do not comply with a design specification (Milberg 2006).
Lack of state of the art	Unlike manufacturing, the construction industry has no widely accepted method for developing and optimising tolerances which serve a key role in quality, accurate fit in the assembly process, cost, and cycle time of end products (adopted from Creveling 1997), although there have been advances in design process to communicate tolerances (e.g. Ballast 2007; Milberg 2006). Optimal tolerances lead to obtaining maximum component function and correct fit in assembly processes.
Incomplete drawings	Drawings with incomplete or wrong tolerance specification may result in deficient connection details, selection of incompatible materials or assemblies that are not constructible (Feld and Carper 1997), uncertainty on site, tolerance problems, and rework (Seymour et al. 1997). Uncertainty here means when contractors do not know how to fit components, and deal with interfaces.
Inefficacious standards on tolerances	Current construction techniques require the use of a combination of factory-built and site-built components assembled in complex ways. It is more important than ever to refer to standards and understand what normal tolerances are, how they can accumulate during construction, and how to plan them before they cause problematic issues (Ballast 2007). However, standards on tolerances are not widely considered in the industry and tolerances are often replicated from similar previous drawings (Mavrikas et al. 2015). The following reasons are the main drawbacks of tolerance standards: (1) there are still many construction tolerances that do not exist as industry standards (Ballast 2007); (2) standards are often based on consensus opinion of the committee participants, not on empirical data (Milberg, 2006). Hence, they are unable to specify functional requirements when annotating a drawing (Mavrikas et al. 2015); (3) there are different versions of standards and sometimes companies have their own internal standards. Dissonance in standards incurs tolerance problems when using different standard systems (ACI Committee 1990).

Lack of education	Students receive rudimentary education for tolerancing. In fact, tolerancing is perceived to not be teachable in school but only trainable on site while Feld and Carper (1997) argue that "*education is an essential component of any failure mitigation strategy*".

Table 2: Extrinsic Factors

Factors	Description
Materiality of elements	Seven scenarios are probable for materials and components in the realm of tolerances: (1) they may not meet the specified dimensional tolerances and have a poor quality, (2) adjacent components lack a uniformity of dimensional accuracy (Koskela 2000), (3) all materials exhibit reversible or permanent dimensional changes as a result of physical (e.g. stresses) or chemical causes (BS 6954-1 1988), (4) tolerances specified for a manufacturer may be either unreasonably tight and increase the production cost of components or they are loose and remedial actions must be taken to ensure components will fit properly, (5) a lack of information on dimensional tolerances of components made either in factory or on site, (6) critical dimensions of all components may not be inspected in a factory setting, and (7) components may become distorted during transportation to site, while components are often measured on site only visually and it is unlikely to recognise out of tolerance components prior to the process of assembly.
Undeveloped/ Expensive Technology	BIM and advanced measuring instruments are new technologies that can greatly contribute to TM process. BIM enables better control of spatial dimensions and tolerances (Sacks et al. 2010), 3D modelling of interfaces, detecting physical clashes of components, receiving tolerance specifications from manufacturers and assigning them to components, and comparing as-designed models and as-built models to measure deviations from specified dimensions. However, BIM is not sufficiently developed to automatically assign tolerances to components; detect the tolerance incompatibility of adjacent components; analyse required joint capabilities to mitigate the effects of tolerance problems; consider added thickness due to fire proofing spray and grout, inevitable dimensional variations resulting from movements and changes of size of materials, and etc.; and accumulate tolerances and assign real tolerance values that consider the worst case in which component dimensions are at their tolerance extremes or component members are placed at the extreme location allowed by the stated tolerances. Measuring instruments which have a higher level of accuracy are often more expensive and unaffordable compared to conventional instruments.

Unsatisfactory performance of building: Depending on their severity, tolerance problems may affect the performance of the completed building by: (1) producing eccentricities of loading, reducing areas for load bearing, inducing stresses and damaging structural stability (BS 6954-1 1988), (2) damaging the appearance of the building aesthetically (BS 6954-1 1988), and (3) creating poor indoor conditions such as acoustic problems, and issues with flat and level surfaces.

EXSISTNG METHODS FOR TOLERANCE MANAGEMENT

Two methods are often proposed for the improvement of TM. The benefits and drawbacks of each are discussed below.

INTEGRATED DESIGN AND CONSTRUCTION

There is a general consensus on the need for integrated design and construction, as site problems are mostly caused by poor integration (Alshawi and Underwood 1996). Integrated design and construction helps to eliminate tolerance problems proactively at the design stage, while a lack of coherence between design and construction results in quality problems. However, Minato (2003) states that the industry tends to focus on failures including tolerance problems only at task or activity level and then corrects the defects on site. This is because:

- although the industry's recent trend is to incorporate all details in the design to reduce the problems on site, this action does not necessarily result in better performance (Love and Josephson 2004). Spending time on inspection and co-operation in design can sometimes cost more than dealing with them on site. To overcome this problem, the ACI Committee (1990) suggests that statistical analysis is required to (1) balance the cost of correction and customer dissatisfaction against the cost of precision layout and a more rigid tolerancing process, (2) make decisions on having tighter tolerances against wider joint flexibilities in components, and (3) optimise the construction cost by revising the design specifications.
- designers traditionally neglect continuous improvement in design (Koskela 2000), even though this is imperative for improved TM.
- as implied earlier, tolerance problems affect the quality of the end product while less attention is paid to quality management during the design stage, and designers presume common practices will remedy the problems (Love et al. 2009).
- designers are under the pressure of tight schedule to finalise designs.
- designers are perceived to be responsible for addressing the tolerance problems. (Alshawi and Underwood 1996). However, they lack the understanding of site conditions, tolerance incompatibilities, and design constructability.

Construction input into the design process (integrated design and construction) is necessary to reduce tolerance problems (Alshawi and Underwood 1996). There are two preconditions to accomplishing integrated design and construction, and improving TM:

(1) establishing a continuous process that aims at mitigating tolerance problems, optimising tolerances, and improving quality systems, design process and legal systems (Minato 2003). The process must be holistic, which means it must be initiated at the early design and must continue throughout the project until handover;

(2) using an IT-based system which enables designers to test the constructability and impact of their design on the construction process (Alshawi & Underwood, 1996), to simulate interfaces between elements and predict their performance (Kieran and Timberlake 2004), and to generate designs that include reasonable tolerances.

BIM tools are comprised of both of the aforementioned preconditions. It is envisaged that they can potentially reduce tolerances in the factory setting and minimise tolerance problems during production. However, BIM is in its early stages of development in the field of TM and needs to be developed further to fully incorporate both preconditions.

INDUSTRIALISATION

Industrialisation aims at remedying the chronic problems in construction (Koskela 2000) in order to change the culture that ignores waste (Roy et al. 2005). Although the concept of industrialisation has demanded much attention recently and been widely propagated through the industry, Koskela (2000) believes that it is yet to be successful. Applying industrialization to the construction process, with the aim of converting a conventional process into manufacturing, does not necessarily remedy the current problems (Koskela 2000), and can in fact exacerbate the situation. In other words, industrialisation is often considered only as a way of manufacturing components in factory. But it is primarily about establishing effective processes that are adopted by the workforce to streamline activities, improve efficiency and quality (Roy et al. 2005), and move from being project-based towards a process that takes continuous improvement into account.

Although industrialisation is perceived to reduce the interface and tolerance problems (Holroyd 2003), this technique has four drawbacks that impede the improvement of TM:

(1) since the manufacturing process itself can create much waste (Koskela 2000), factory-production does not necessarily mean a zero tolerance problem.

(2) industrialisation of some sectors has been faster than other sectors and accordingly some sectors have a higher dimensional accuracy. This misalignment between different sectors results in adverse consequences, particularly when these two types of elements are assembled besides each other (Koskela 2000). In this situation, it is vital to provide adequate control, extensive training, and an effective feedback process to identify potential problems and avoid concealing any such issues.

(3) even though standardisation aims at reducing variability and uncertainty on site, this technique can itself sometimes increase both of these. Components are produced in factories, independent of the final building's design. Tolerance specifications are not communicated to the design team to make a decision for dimensional discrepancies and to anticipate the impact on adjacent components. As a result, tolerance incompatibilities are very probable. Therefore, industrialisation requires an effective co-operation between the manufacturer, design team, and on-site contactor.

(4) although repeated processes help to reduce tolerance problems, a lack of feedback from the workplace on how components are fitted into the process prevents maximised improvement and reduction of tolerance problems (Holroyd 2003).

(5) Industrialisation requires a high level of control over dimensional accuracy while industrialised construction suffers from poor control during both the design and prefabrication stage (Koskela 1992).

CONCLUSION

There is no single TM methodology used in industry, which is widely accepted and applied from the early design stage through to implementation and project handover. To improve TM, it is vital to understand and document the causes of tolerance problems. This paper suggests a concise categorisation for the root causes of tolerance failures, which includes both extrinsic and intrinsic factors. Furthermore, improved TM demands the consolidation and refinement of existing methods and an evaluation of their appropriateness based on feedback from empirical data obtained from industry. After all, the proposed methods must be incorporated into a continuous, standardised, and holistic process that systematically reduces the number of identified problems. Integrating construction input into design and industrialisation are imperative for establishing such a process, although they have their own drawbacks. In addition, the emergence of new technologies such as BIM provides strong opportunities to advance this field, although it still necessitates further development. Raising consciousness and awareness within the industry of the adverse consequences of tolerance problems, and balancing the cost of improved TM against the cost of customer dissatisfaction should not be neglected as these can revise the current perception of the importance of TM for the industry.

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CONSTRUCTABILITY ANALYSIS OF ARCHITECTURE–STRUCTURE INTERFACE BASED ON BIM

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ABSTRACT

One of the main factors responsible for the reduction of the overall performance and efficiency of buildings is poor project management. Studies have found the integration between design and construction processes has become an important requirement for improving project performance. Considering Lean philosophy has the potential to better integrate design and construction activities.

This paper evaluates the request for information (RFI) associated with the interface between architecture and structure of a BIM model. Methodology was qualitative and research strategy was case study of a virtual construction of a residential building in Fortaleza, Brazil, with 15.925,67 m² of floor area and an estimated cost of $9, 2 million dollars. 260 RFI were analysed, 110 of which were associated with conflicts between structure, architecture and the MEP systems. That represents 42% of the total RFIs, the highest percentage among other RFI categories, such as plumbing systems, architecture vs. MEP, electrical systems, architecture, and fire protection and gas systems.

This study aims to improve the architecture-structure design interface, and to assist virtual construction crews on what to watch for and how to identify design problems before they are taken to construction site.

KEYWORDS

Constructability, VDC, BIM, RFI, Lean.

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INTRODUCTION

Building Information Modeling (BIM) can assist AEC industry to find potential problems before construction begins (Sacks and Barak 2006). In addition, some benefits of BIM related to design compatibility are maximized through Virtual Design and Construction – VDC.

Requests for information (RFIs) are generated in virtual construction phase. RFI allows the opportunity to identify design problems or improvement that would otherwise be detected only during construction phase, where there is risk of delay and productivity loss. Despite the importance of RFIs, there has been little research to understand how they happen, for what reason they happen, and which strategies can be created to avoid them.

This research is justified by cost implications of a RFI in construction site. Such cost, calculated solely based on administrative and technical review of RFI, was a little over U$1,000 each (Hughes et al. 2013).

The goal of this study is to describe and analyze RFIs by applying qualitative analysis and propose a proactive approach in identifying and solving design problems. The classification of design errors provides the foundations to consider the appropriateness of strategies to contain and mitigate errors (Lopez et al. 2010). This work is focused on RFIs associated with a BIM model of a structural design with a level of development 400. This work contributes to gap observed in the literature to better determine the strategies needed to significantly reduce design errors in construction and engineering projects (Lopez et al. 2010).

BACKGROUND

This section summarizes literature review that was performed in relevant subject areas including Virtual Design and Construction (VDC), constructability and qualitative analysis.

VIRTUAL DESIGN AND CONSTRUCTION

Virtual Design and Construction – VDC – consists in using multidisciplinary computer models that contain performance targets, construction timelines, and data on organization of the construction and operations teams to promote a better integration among architecture, engineering, construction, operations, and business strategies. (Fischer and Kunz 2004). The main goals of VDC are to use 4D models to create alternatives for projects and anticipate their behavior and performance (Breit et al. 2008). Studies show VDC triggers Lean construction and improves performance of design-construction delivery (Khanzode et al. 2006). VDC is a very effective tool to improve construction management, but its utilization requires significant changes in protocols, mindset and conservative behavior of construction industry (Khanzode et al. 2006; Li et al. 2009).

This work understands Building Information Modeling (BIM) as a set of interacting policies, processes and technologies generating a "methodology to manage the essential building design and project data in digital format throughout the building's life-cycle"(Penttilä 2006; Succar 2009).

CONSTRUCTABILITY

Constructability is a concept that emerged in late 1970's (Alinaitwe et al. 2014; Sulankivi et al. 2014) and has evolved ever since, due to many studies (Alinaitwe et al. 2014; Hussein and Rosli 2010; Pulaski and Horman 2005; Sulankivi et al. 2014). It can be defined as the use of construction knowledge, project planning experience, engineering, and supplies for design optimization (Othman 2011). This paper proposes a constructability analysis framework that aims to reduce construction problems caused by poor project planning and to make design companies more competitive (Jiang et al. 2013). When associated with design process, constructability increases quality and productivity while reducing time, waste and costs, and promoting better building performance since it brings contractors to design onset (Motsa et al. 2008).

A constructability information classification scheme is proposed in this study and can be used to capture, store and retrieve knowledge of constructability (Hanlon and Sanvido 1995). Six different constructability concerns are proposed and from the moment constructability issues are categorized, a new type of constructability thinking about design process interface is presented (Jiang et al. 2013). Such categories and constructability concerns have been adapted to analyse RFIs of residential projects and a new list of categories is proposed: *Design Correction; Divergence of information; Design change; Design failure; Validation information; Design verification* (Dantas Filho et al. 2015).

METHOD

This study was classified as exploratory and descriptive. The unit of analysis of this work is Request for Information. Methodology is of qualitative type. Initially, it started with the question: "How requests for information can contribute to improving architecture – structure design Interface?" Then we carried out a literature review for the subject and for the method.

Research strategy adopted was case study (Yin 2001). The case choice was through "selection information-driven" to maximize usefulness of information according to research objectives (Takahashi 2013). The case chosen was supposed to contain the use of VDC in coordinating designs with documentation of requests for information. Thus, a case was selected to obtain information allowing logical deductions. As an example, "If this does (not) apply to this case, so it can (not) be applied to other cases."

Data collection was based on multiple evidence sources: deep analysis of documents and interviews. Three *coordination models* based on Autodesk Navisworks software were analysed. For the purpose of this study, a *coordination model* is the model that contains virtual construction process of all project disciplines and was modelled in Autodesk Revit software. The *coordination model* documented RFIs identified by design coordinator consultant. Semi-structured interviews with the coordinator of virtual construction were held. The following operational procedures were undertaken to legitimize and assure the reliability of data collected: review of interview report by interviewee and development and use of case study database (Yin 2001).

Data analysis was based on recognition of patterns, development of explanations, and use of logic models. Empirical pattern obtained from the case study was compared to another from a prognostic basis, obtained through literature review. This study performs the analysis of general RFIs categories previously proposed by literature (Dantas Filho et al. 2015; Hanlon and Sanvido 1995; Jiang et al. 2013), but is not limited to them. The study identifies new categories that emerge from the typology of analyzed data. The methods used for classification of data were the principles and practices of coding (Gray 2012).

The "requests for information" contained in BIM models are short communication messages written by the virtual constructor to client and project teams. It is always associated with an image of virtual construction and summarizes the issue. The categories proposed in the table of results in the end of this paper – that explored pattern recognition – are the synthesis of this short communication. Therefore, they are not limited to literature review and new categories may emerge from data analyzed.

RESULTS

BUILDING DESCRIPTION

The analyzed building is a 15.925,67 m² residential tower with an estimated cost of $9.2 million dollars. After conclusion of architecture, structure, and systems design, the developer-construction company – the client – decided to undertake an extra step called virtual pre-construction. A BIM model was then created, with a level of development 400, as a tool to evaluate project's constructability. This analysis intended to foresee any challenges that construction systems might present, assuring that systems would be executed efficiently, kept within the budget, and on schedule. In order to meet client's demand and fully achieve benefits of BIM, the building company provided the virtual construction team their construction method. The construction method contains information about project's execution that are not explicit in design set, but that were taken under consideration by virtual pre-construction team.

CASE STUDY'S VIRTUAL PRE-CONSTRUCTION

Through the analysis of 260 RFI in three BIM models, a total of 110 requests for information associated with clashes between Structural, Architectural, and systems design were identified. Usually, this type of RFIs is only identified during construction. Undertaking the virtual construction before building process starts prevents the construction manager from wasting time with issues that can be solved outside of construction site and really focus on construction planning and execution. Figure 1 illustrates how RFIs, the object of qualitative analysis in this paper, are distributed. The graphic in Figure 1 shows the value of the process and its possibilities since all RFIs identified can be addressed. This figure makes it clear how much value BIM brings to the table. BIM helps transform design and construction processes, in what enhances project quality, eliminates conflicts, and reduces rework, benefits likewise demonstrated by previous work. (Chen and Luo 2014).

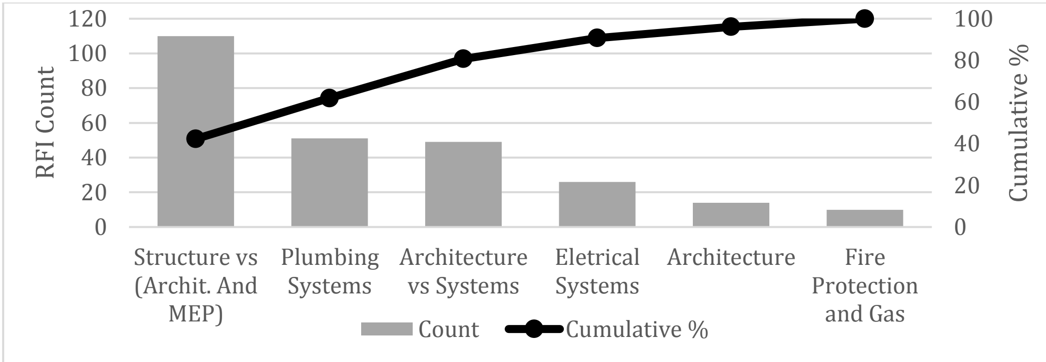

Figure 1: Design distribution of the RFI identified

Interview analysis showed that virtual construction process of design was developed in three steps. In *step 1,* 3D models of architecture and structure were created, establishing an RFI report focusing on the interface between these two design projects. In *step 2*, models of systems utilities were created. The team then performed a constructability analysis of design using a *coordination model* that contained 3D models of all projects. In this stage, a report containing all identified RFIs was prepared. The designers responsible for each discipline then performed the analysis and review of their projects and issued new versions. *Step 3* then started, and the virtual construction team analyzed new versions of projects, observing new solutions given for the issues raised. A final report was issued to the builder-developer consisting of unsolved RFIs and new issues that arose as a result of modifications made by the design team.

General RFI Classification

RFIs identified were classified in four categories: *Correction, Omission, Verification*, and *Divergence* (Dantas Filho et al. 2015). Figure 2 illustrates RFI reduction in each general category. Three 3D models created during *steps 1, 2*, and *3* of VDC process are indicated below. Left vertical axis shows the total RFI identified by *step*. RFIs generated by analysis were categorized and their count is shown in right vertical axis of the graphic.

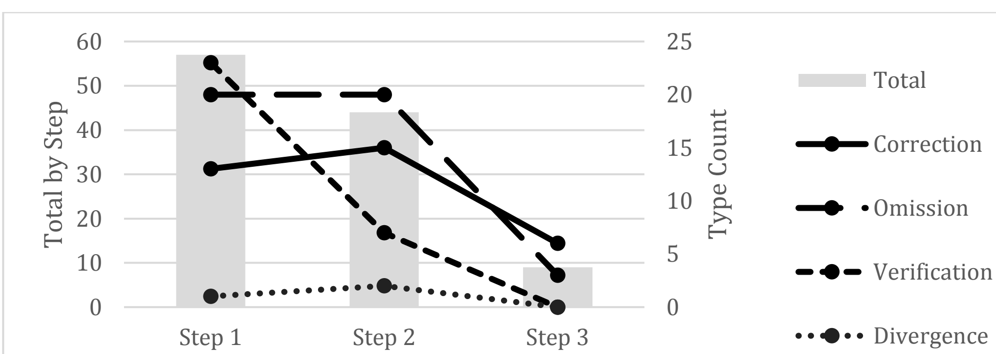

Figure 2: Reduction movement of RFI general types sorted by Step VDC

Below, a description of the RFI categories discussed in this paper followed by examples taken from the case study at hand.

Correction is a problem associated with technical feasibility of solution presented in design, and it usually occurs due to incompatible design versions. For example, the structure was not aligned with masonry walls as defined by architectural design. If this issue does not get solved before construction, consequences can cause reduced width in corridors and fire stairways, which will result in unconformities with firefighting project. Other examples include misplaced pillars in structure vs. architecture design project, insufficient floor-ceiling height, and general misalignment between structural and architectural projects.

Omission is absence of specific design elements required for some areas. For example, in the case study at matter in this paper, there is a vertical displacement platform for people with disabilities not placed at the same level as floor slab. To solve this problem, a ramp would need to be created, which generates a new demand for space not addressed by architecture. Other examples include an unplanned void between floors was identified and will need an embankment on ground, and a recess below lifting platform that was not designed and now will be required

Verification are cases where design is not necessarily wrong, but it offers opportunity for improvement. In this case study, the bottom of internal joints is on same level as the bottom of structural joints on the porch perimeter, which means that they will necessarily intercept ceiling panels. This certainly was not the intention of the architectural project, which planned a continuous ceiling with no interruptions. Checking the possibility of reducing internal beams height would have solved for this problem

Divergence indicates that two or more different drawings have inconsistent information. In this case study, the architectural design proposed a pool with curved edges, whereas the structural design proposed edge to be partially straight on the same section. This happened because the structure designer took into consideration the floor-ceiling height of the underground floor, which houses a parking lot and other functions that require a minimum height. Better communication between two design teams could have avoided this type of situation, which needs to be discussed by both sides rather than solved by unilateral decisions. This put under risk the owner project requirements and the architectural value of the project. Other example of *Divergence*: structure beams of facade diverges from walls from the architectural design.

SPECIFIC RFI CLASSIFICATION

Besides general analysis discussed in previous section, this paper proposes a specific classification of the requests for information associated with structural projects. Such classification is the result of the coding process and is in accordance with a system that comes from data itself. These specific types of RFI are shown in Figure 3 and look deeper into the general RFI categories types previously explained. It is observed RFI on *Conflicts* were the major occurrence, followed by those on *Poor alignment* and *Structure Absence*. These three types together account for 89% of the total.

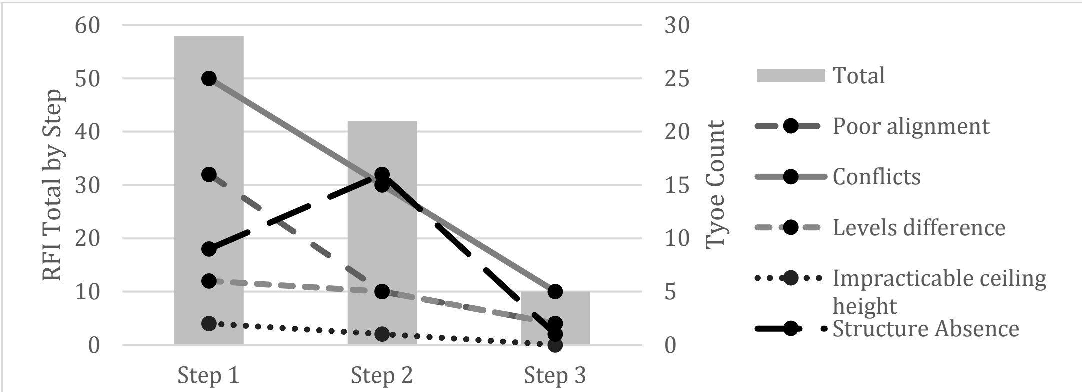

Figure 3: Reduction movement of RFI specific types sorted by Step of VDC

Examples of *Poor alignment* happen between structure and walls and between pillars and joints. Some consequences of *Poor alignment*: area reduction, aesthetic interference, extra spending on fillings. All that can jeopardize the architectural concept, which can lead to non-compliance with the owner's requirements.

Example of *Conflicts*: pillars and beams occupying a considerable area of parking spots, and pillars or beams that intercept windows and doors. Based on examples given, *Conflicts* generate consequences such as: decrease in the number of parking spots, difficulty to perform car maneuvers, reduction of windows and doors openings area, or in the worst case scenarios, it makes fenestration useless.

In this case study, *Levels difference* are problems caused by uneven levels between street and property, street and garden, and between floor and elevators. *Levels difference* affects the property access and generates extra expenses with filling.

Impracticable ceiling height means that ceiling is compromised by height of beams or slabs. It affects, for instance, fire escape routes. In this case study, the VDC team identified a floor-ceiling height of approximately 1.6 meters in fire scape route due to low beams.

Structure Absence is when the building element cannot be implemented due to a lack of a load bearing structure. It is a severe issue because it usually affects the building safety directly and it generates considerable delays in construction schedule since construction site team has to await development of the missing projects or elements.

KEYS TO A SUCCESSFUL RFI REDUCTION

Identifying conflicts is a reactive approach, whereas avoiding conflicts is a proactive approach. That said, ways to improve design process are necessary to reduce future conflicts to occur (Tommelein and Gholami 2012). Table 1 offers a few recommendations as a guideline to identify and avoid RFIs associated with clashes between Architectural and Structural designs.

Table 1: How to reduce RFI – ways to identify and avoid

	RFI Types	Action
1	Correction	Check alignment between structure and architecture; check floor-ceiling height
2	Omission	Check whether there is structural design for all project components; in projects with variable floor plan, check for variations in the formwork plan; check for floor recess for lifting platforms
3	Verification	In the porch area, design the bordering beam with greater height than the inner beams to better accommodate the ceiling panels
4	Divergence	Check heights consistency between Structural and Architectural design projects
5	Poor Alignment	Agree on the same starting point for the building construction; observe walls thickness vs. thickness of the beams that hold them up; architecture team should clean up the drawings from superfluous information that can lead to misinterpretations before hand over those drawings to other design teams
6	Conflicts	Agree on the same starting point for the building construction; architecture must make its requirements clear before the pillars are set on place
7	Level difference	Designers of all disciplines should agree to use the same level of reference; special attention should be paid when inverted and semi-inverted beams are used; observe proper thickness of the layer of soil for gardens
8	Impracticable ceiling height	Architecture design team should provide maximum limits for beams height> if not possible, they should check the drawings back after Structural design is ready before the final project goes to the construction site. That would greatly avoid conflicts in the floor-ceiling height.
9	Structure absence	The structural design of all building elements should be developed before construction, be it real or virtual construction

These actions and strategies presented in Table 1 is intended to be a guideline for other virtual construction teams, a reference on “what to look for?” in a BIM model as far as clashes not automatically detected by software. It is also useful for design team – especially the ones working with projects based on BIM – in what it helps them to avoid frequent design errors. Table 1 could form the basis of a formalized design review procedure.

For instance: in projects executed with maturity level pre-BIM (Succar 2009), the MEP designers do not have control over level of tilted pipes. Only designers undertaking processes with maturity level BIM-2 would have the ability to actually visualize pattern of tilted pipes and identify whenever they overpass a given design guideline. At that moment, designer in charge would have chance to correct de project, modifying pattern and avoiding RFI.

CONCLUSION

Although any design has its own specific characteristics, it is observed the results from this study can serve as a reference for proactive approach in what concerns to identifying conflicts, as proposed in previous studies (Tommelein and Gholami 2012). That said, it is suggested the checklist of Table 1 can be used directly by design teams as a guideline for identifying conflicts and inconsistencies. There is no single strategy, but a multitude of strategies that need to be adopted in congruence to reduce design errors (Lopez et al. 2010).

Virtual construction process has ability to demonstrate the potential for minimizing number and magnitude of changes, disputes, budget increases, and delays during construction (Alinaitwe et al. 2014). Based on this, it is believed that the RFIs generated in the case study and discussed in this paper can contribute to enhance design processes, production, and construction management of projects throughout. In order for that to happen, RFI strategy should be considered during integrated design process in which participants are committed to eliminate potential RFIs making the process more lean.

The use of RFIs as a tool to enhance project management not only can minimize how often design errors happen, but also make the design more time-and-cost efficient, by avoiding rework (Lee et al. 2015).

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VIRTUAL DESIGN AND CONSTRUCTION LEANER THAN BEFORE

João Bosco P. Dantas Filho[1], Bruno M. Angelim[2], and José de Paula Barros Neto[3]

ABSTRACT

Virtual design and construction is turning into a more essential service to develop construction designs. Builders-developers are demanding virtual design and construction even in pre-BIM design processes. In this context, companies specialized in virtual construction need to get ready to meet its increasing demand. The aim of this study is to identify how virtual design and construction process works to suggest improvements from lean construction tools. Based on a qualitative methodology and through lean construction diagnostic tools to collect data, process structure elements are described, stream mapping are designed, cycle times are analyzed, restriction are identified, process changes are suggested. Through feedback from case study respondents, this research has concluded that there would be a meaningful improvement in global productivity and decrease in total amount of time.

KEYWORDS

Value Stream Mapping, virtual design and construction, VDC, BIM, Lean construction.

INTRODUCTION

In the markets of low level designs towards BIM maturity, leading companies develop their work through traditional design processes. Although this scenario, contractors, who have understood BIM competitive advantage, demand BIM services, even in processes of situated projects in pre-BIM stage. In this context, companies specialized in virtual construction rise and work in an intermediate stage at the end of projects and before construction. Contractors are interested in design compatibility; quantity takeoff; and production planning. Currently, the meeting of these three goals in one stream is named after the new preconstruction. The study of office-related activities, when it comes to preconstruction phase, has been overlooked (Reginato and Alves 2012).

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The trend is virtual construction becomes a more essential service in design process and virtual construction companies must make effort to meet demands. On the other hand, designers gradually and eventually need to implement radical changes to increase the level of BIM maturity in design markets.

There is a lot of waste in current virtual design and construction (VDC) practices (Mandujano et al. 2015). A few studies have been applied focusing on the VDC processes inefficiencies. Then improve the performance of processes based on BIM from the application of lean principles is a knowledge gap observed.

The goal of this research is to suggest improvements in virtual construction processes from a lean perspective. The contribution is highlight opportunities for improvement of virtual construction process and to meet demands associated with a more essential service in low level BIM-maturity markets.

BACKGROUND

VIRTUAL DESIGN AND CONSTRUCTION

In this paper, VDC is understood as a methodology, which uses models based on multidisciplinary computers in construction field, including product (the building), design organization, construction, operational team, economic processes and outcomes (quality, cost, time) to support objectives of integrating design, construction, operations and business strategies (Fischer and Kunz 2004).

VDC is considered a structured process, a set of measurable activities conceived to produce a specific outcome (Mandujano et al. 2015). VDC is contained in Building Information Modeling knowledge domain, which is more embracing. BIM is a growing research field, incorporating several knowledge domains in architecture, engineering, construction and operation industries (Succar 2009).

LEAN CONSTRUCTION TOOLS

Lean Tools can be applied in hospital flows (Henrique et al. 2015), in shoe factories (Lima et al. 2016), in construction companies (Bulhões et al. 2005; Pasqualini and Zawislak 2005), in processes of housing projects (Leite and Neto 2013), in power plant processes (Venkataraman et al. 2014), in automatized assembly lines (Azizi and Manoharan 2015), in the development of software products (Ali et al. 2015).

Lean tools have been developed and applied with success in construction industries worldwide. Such tools can generate benefits as they improve company's organization, its development and competition as well (O'Connor and Swain 2013). They can be grouped in two types: diagnostic tools and improving tools (O'Connor and Swain 2013).

METHOD

This study is classified as a functionalist epistemological paradigm. Analyze how VDC processes work, makes it possible to propose improvements, and the suggestion of benefits to stakeholders. Virtual construction process is our research topic. Research strategy is case study, since there are questions such as "how" and "why"; the focus is on contemporary phenomena in real-life context (Yin 2001). We began with the question: "How is it possible to improve virtual construction process?".

Figure 1 shows research's first development, which presents as its first step the literature review about research topic and also about improving strategies based on lean philosophy. Literature evidences have contributed to protocol design in data collection, which was the second step in this study. The choice for case study happened through information-oriented selection (Takahashi 2013) to maximize collected information utility to reach our goals.

Next step was data collection in field by the case study application. At this moment, interviews with professionals from specialized companies were conducted. Then, collected data were analyzed qualitatively and result was elaborated according to chosen lean tools. Following step was going back to the case study company, and interviewing again its professionals in order to obtain validation and review of qualitative data and of the proposed improvements as well. Necessary corrections due to professionals' feedback were realized and, then, last step could be applied: the case study final report.

Figure 1 – The research development

Some lean construction promoted tools were used, focusing on process diagnosis. They are SIPOC Map, Swim Lane and Value Stream Mapping (VSM).

SIPOC presents process elements structuring, synthesizing description and facilitating understanding. SIPOC is a process of more detailed characterization to help design a "customer-centered" process (O'Connor and Swain 2013).

Swim Lane Diagram allows us to see stream and changes between participants.

VSM is about surveying all actions to come up with a raw matter product to customer, since its conception until its release (Rother and Shook 2003). Besides, VSM focuses on flow and time variable analysis.

RESULTS

CASE STUDY'S VIRTUAL CONSTRUCTION

This research is situated in a context which design companies have a low BIM maturity level. In this context, the practice of virtual construction specialized service occur after designs' conclusion developed by traditional process. For contractor, which is a constructor and an incorporator, the requisites are design compatibility and emission of BIM-based quantities.

The company in case study has already worked with 9 different hirers and incorporators. It has virtually built the total of 13 multifamily houses, as shown in table 1. These constructions represent 60% of the 440.000m² total set virtually built.

Table 1: Set of multifamily housing virtual construction

Work	1	2	3	4	5	6	7	8	9	10	11	12	13
Area (m²)	11.780,00	12.643,00	15.144,62	16.539,00	17.316,00	17.597,10	17.791,46	19.483,72	20.601,00	21.212,00	26.967,00	28.147,00	33.427,30

SIPOC MAP

With the aim to describe virtual construction process of this case study, table 2 reports following elements: Supplier, Input, Process, Output, Customer. Research's focus lies on process element.

In planning process, an engineer receives all design documents and checks them in order to conclude if designs are complete. Frequent identified examples are the absence of an element structural design as security cabin and crowning of building. This stage produces templates of virtual construction files. With specified constructive elements, these templates are defined by premises from design analysis. The idea is molding of building elements following denomination, specification and standards of design and its analytical structure.

In modeling process, construction technicians virtually build design models in Autodesk Revit software. Structure and facility models are built from the company's digital collection templates, while architecture models are built from template created by planning process specifically designed for work.

BIM analysis receives 3D models from courses and creates the coordination model. In this process occurs a software change for the Navisworks Manage. A civil engineer navigates through the model to be aware of questions that could be only visualized physically in construction site. Information requirements are added to coordination model and this 3D model containing an info requirement note panel is the report. Contractor and designer can access the model and its information through the software Navisworks Freedom, which is a free 3D viewer to Navisworks' NWD file format.

The 5D emission process generates numbers extracted from 3D models through the Vico Takeoff Manager software. But it can be only developed after the effort of designers equalizing their designs and after virtual construction team update their models. This stage contributes so the budget activity time is not invested in quantitative survey task, but the budget engineering happens with a reliable basis in the quantities.

Table 2: Case Study's SIPOC Map

Supplier	Input	Process	Output	Customer
Designers and builders-developers	Designs, construction method, quantitative assumptions	**Planning**	Checking of design documents and creating the architecture template	Modelers
Planner	Template and projects: structure, architecture, sanitary plumbing, fire fighting, water plumbing, electrical and communication	**Modeling**	BIM Model: structure, architecture, sanitary plumbing, fire fighting, water plumbing, electrical and communication	Following modelers, BIM analyst Emitter 5D
Designers and Modelers	All disciplines Projects and BIM Models	**BIM Analysis**	Review of BIM models and analysis of constructability	Designers builders-developers Emitter 5D
Modelers BIM analyst	BIM Models fixed, construction method, quantitative assumptions	**5D Emission**	Quantity Emission based on BIM	Builders-developers

SWIM LANE

Figure 2 presents activity stream and information exchange between professionals of the virtual construction team in this case study.

A modeling sequence inspired in "real world" construction sequence was noticed. This spreads out the fact that the modeling sub process of each course becomes an inward client of previous stage. Architecture modeling is applied in a virtual environment that already sees structure. Sanitary plumbing is first setup to be modeled by other setups. Water plumbing and firefighting gear are done by the same modeler in charge of sanitary plumbing. Finally, communication and electrical installation courses are modeled by "detouring" from previous modeled elements.

Continuous stream is interrupted by passage from BIM analysis to 5D emission. That is so because at the end of BIM analysis, design reviews are done by designers. This takes about 30 to 90 days waiting, according to interviewed virtual construction coordinator. After emission of new design versions, 3D models need to be adjusted to new designs. At this moment, virtual construction team always makes following question: "do we change it or remake it?". Then, depending on quantity or complexity of changes, making a new modeling of design may demand less time than identifying differences between design versions. At the end of the process, emission of the model quantities can be accomplished.

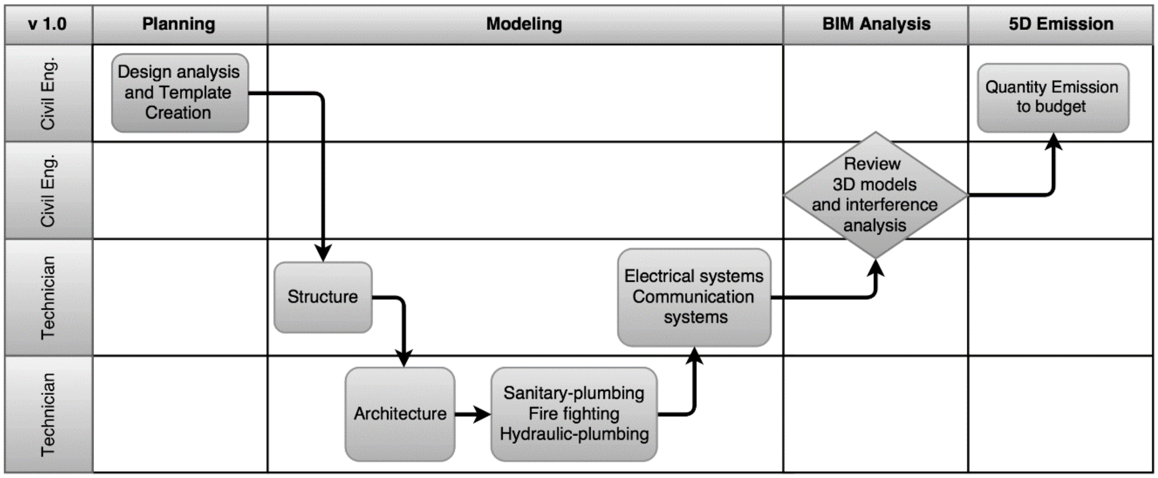
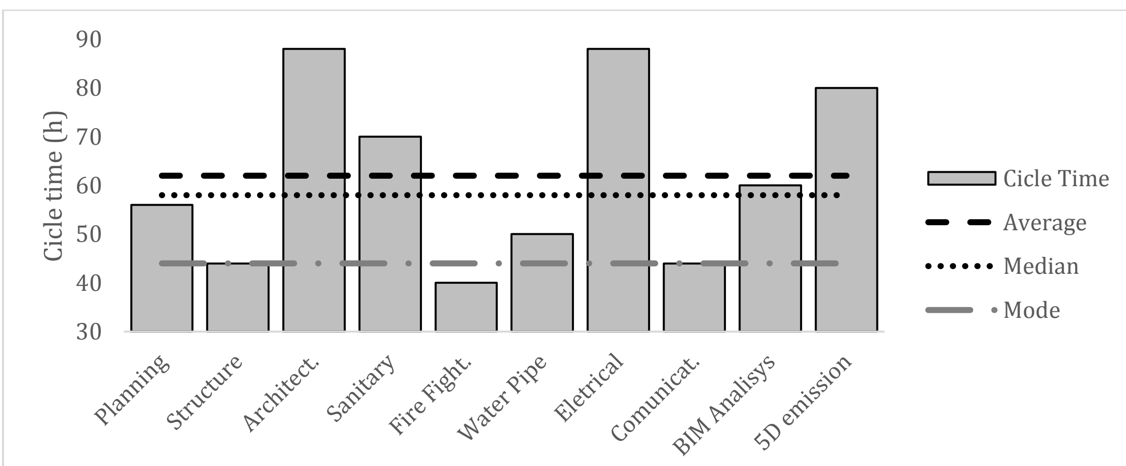


Figure 2 - Swim lane of the virtual construction process

CYCLE TIME

The time to accomplish each virtual construction process was informed by professional responsible for the interviews. This time is a personal perception depicting reality, which may be different towards the design complexity. Figure 3 shows the cycle time analysis, as well as the average, median and mode. Activities that demanded time superior to average stand out. Activity time average is understood as takt time for virtual construction process (Hicks et al. 2015) .



VALUE STREAM MAPPING

Value Stream Mapping presented in figure 4 stands for current stage of the case study, while figure 5 shows the proposed future stream. Through occasional implementation of proposed changes is expected to save time

According to the future work stream proposed, it was recommended that structural modeling is done along with planning. That is possible once design document checking,

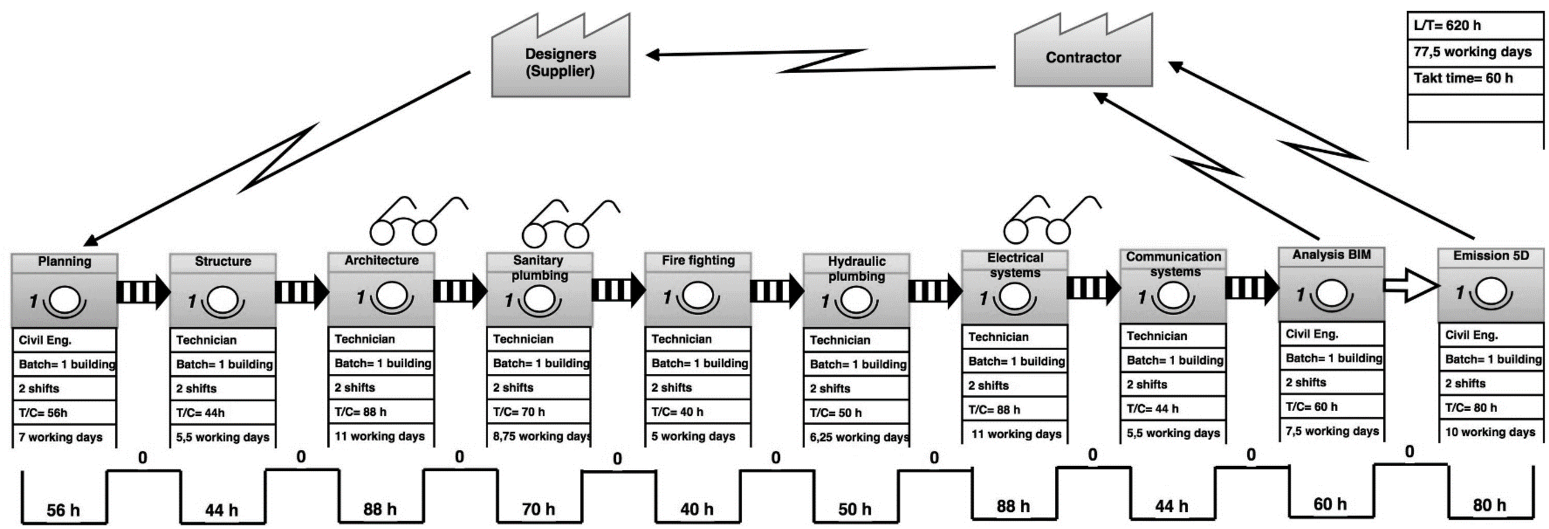


Figure 3 - Current state VSM

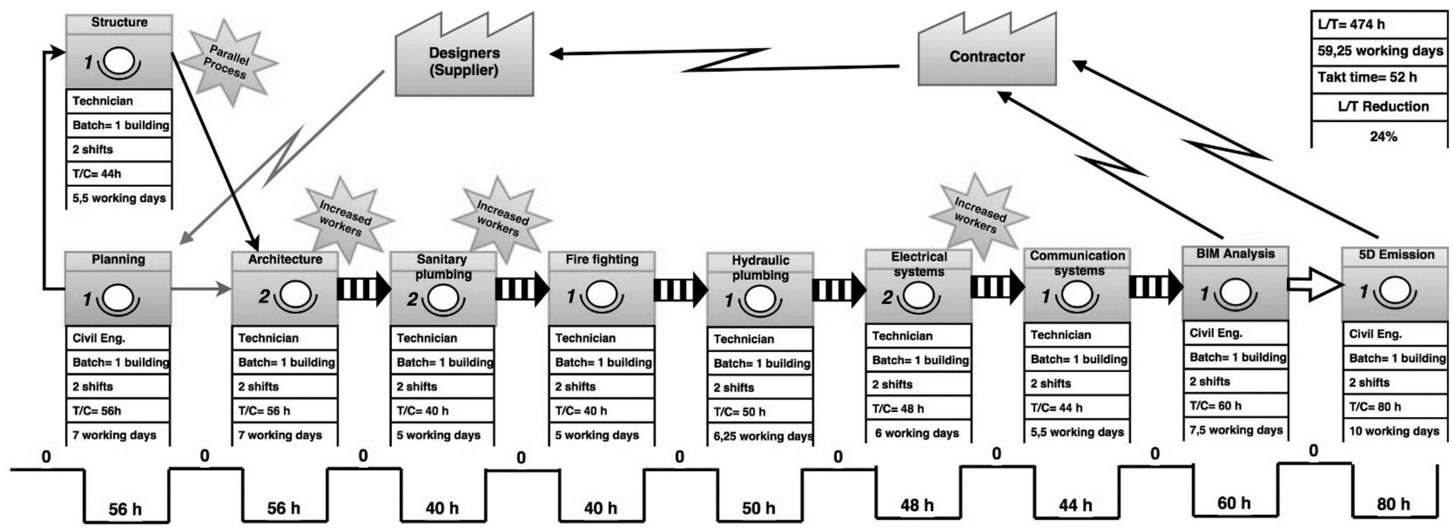


Figure 4: Future state VSM

planning task, develops structural document checking in first place. It was also suggested creation of smaller batches for cycle time designs superior to Takt time. Separation of design into two smaller batches allows team to split effort and work in parallel. Taking that into consideration, cycle time in the future stream corresponds to the Batch 1 time of each changed design (Table 3).

Table 3: Batch Reduction Proposal

Design	Batch 1	Time (days)	Batch 2	Time (days)
Architecture	Basements	7	Tower	4
Sanitary plumbing	Connector Pipe	5	Main Stack	4
Electric Systems	Tower and Electrical Supply	6	Basements	5

Results show the possibility to reduce virtual construction lead time in 24%, if proposed changes are implemented.

CONCLUSION

Through lean tools, it was possible to visualize all virtual construction process and identify opportunities to offer improvement. The application confirmed the literature review, allowing us to state this technique is extremely important to have a better understanding of processes in general, including virtual construction.

Characterization of each activity, visualization of stream and time survey allows us to identify stages of process most distant from takt time of virtual construction process. Therefore, aiming lead time reduction is possible to accomplish the proposals of studied improvements by lean construction.

As a suggestion for future studies, we recommend the following of virtual construction companies with modified processes from action plans created through diagnostic tools and lean construction improving tools.

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ASSESSING SUITABILITY OF TARGET VALUE DESIGN ADOPTION FOR REAL ESTATE DEVELOPERS IN BRAZIL

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ABSTRACT

Target Value Design (TVD) has shown positive results on schedule, budget and products' delivery with higher benefits for the owner. Familiarity with basic requirements of its elements and collaborative business practices have been hallmarks of successful TVD adoptions, particularly in healthcare. However, there has been little discussion about the TVD suitability for the real estate market so far, particularly when the project is driven by developers as opposed to users. Furthermore, the Brazilian real estate context poses some characteristics that could challenge the adoption of the TVD benchmark successfully. Therefore, the research puts forward the proposition that the adoption of the current TVD benchmark for developing products for sale in the Brazilian real estate sector poses some challenges and opportunities for strengthening TVD benefits in this environment. The aim of the research is to discuss about the adoption process of the TVD elements, in order to provide benefits for real estate developers in Brazil. The authors also intend to raise new research questions to better guide its future adoption in this situation. Evidence from an exploratory case study in Brazil is used to support the claim that the benefits already gained on traditional TVD situations, i.e. where clients build for their own use, seems to be insufficient alone to motivate Brazilian property developers to change from traditional practices. Initial assessment shows that, among other TVD benefits, developers acknowledge the improvements for their competitive advantages as the main one, as real estate companies are facing fierce competition currently in Brazil. The findings generate initial discussion about the suitability of the current TVD process benchmark in this context and derive directions for future research.

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KEYWORDS

Target value design, target costing, integrated project delivery (IPD), Real estate, Property developers

INTRODUCTION

The construction industry is a complex business in much of the world. Construction projects are challenging - with demands for schedule restrictions and cost reductions. Projects must adapt to numerous changes during the construction phase, and include urgent revisions, inconsistences in construction sequencing, changes in scope, poor quality etc. (González et al. 2015).

Particularly in Brazil, construction projects are usually developed in an environment where budgetary restrictions and a fragmented and adversarial process of design are common. Traditionally, the design and construction phases of a project are completely sequential to one another and do not overlap. Collaborative practices are not common. On the other hand, Target Value Design (TVD) could be a strategic process to achieve more collaboration in the product development process, which adopts value perceived by the client, as well as cost restrictions, to drive the design process.

The literature reports cases in which TVD has been adopted successfully, promoting high collaborative environments and delivering products with higher added value. In the US, TVD has been used successfully with considerable benefits, such as to reduce costs and add value to the design and construction of health care facilities. TVD applications have increased cost certainty while meeting the owner's demand for increased value (Ballard and Reiser 2004; Macomber et al. 2007; Ballard 2011; Rybkowski et al. 2012; Zimina et al. 2012; Denerolle 2013; Do et al. 2014). Interestingly, the literature has already showed a successful TVD application in non-collaborative environments in the U.S. (Melo et al. 2015). However, to our knowledge there is no such successful TVD application in Brazil so far.

While TVD has been mostly implemented in the U.S. construction industry, particularly in healthcare and in energy efficiency retrofit projects (Lee 2012), the real estate market is a context still poorly explored. The suitability of TVD for the real estate market is still debatable, considering the fact that in this situation property developers drive the project as opposed to users. On the other hand, the benefits offered by the current TVD benchmark (Ballard 2011) include benefits sought by developers.

Particularly, the real estate context in Brazil poses some characteristics that could challenge the adoption of the current TVD benchmark. Some of the characteristics of the real estate context in Brazil are: (i) a highly adversarial and opportunistic behaviour among stakeholders, (ii) lack of awareness of the principles of the Integrated Project Delivery (IPD) (AIA 2007), (iii) a fragmented product and design process development, (iv) the time to launch new products in the market is too long (e.g. three times longer time completion in average than U.S.'s projects according to Mello and Amorim (2009)) and (v) the property developer drives the product development without a systematic process of determining the value proposition of end users. In general, the value proposition exercise is limited to define which product's features would be saleable.

Due to those characteristics of the Brazilian real estate context, the research put forward the proposition that pioneer adoptions of current TVD benchmark in this situation still poses some challenges and opportunities for strengthening TVD benefits. Therefore, the aim of the research is to discuss about the adoption process of the current TVD benchmark, in pursuance of providing benefits for real estate developers in Brazil. The authors also intend to raise new research questions to better guide its future adoption in this situation.

Evidence from an exploratory case study in Brazil is used to support the claim that the benefits of TVD in traditional situations, i.e., where clients build for their own use, are insufficient to motivate property developers to change from traditional practices. As any exploratory research, it poses some limitations. The most relevant one is its impact limitation, as it can suffer from the adopted regional focus approach.

TARGET COSTING (TC) AND TARGET VALUE DESIGN (TVD)

Target costing (TC) originated in the Japanese automotive industry in early 1960s as a cost reduction and value management strategy (Cooper and Slagmulder 1997; Liker 2004; Jacomit and Granja 2011). Traditional cost management practices establish a product´s price by adding a profit markup to a product's design and production cost. By contrast, target costing works from the opposite direction. Considering his own business decision, whether or not to make this or that investment, the developer forecasts the revenues he will receive from sales (or rents) of the product at whatever price he expects to be able to get customers to pay, then subtracts his desired profit margin, and the remainder is the allowable cost—assuming ability to fund. (Equation 1) (Cooper and Slagmulder 1997; Liker 2004; Pennanen et al. 2008).

Target Cost = Target Price – Profit Margin (Equation 1)

If we consider this equation for the real estate sector, the target price is the sales price of the building to be constructed. Estimates of the developer's allowable cost to guarantee his profit margin is used to select characteristics of the building to be constructed.

A traditional pricing model is very different from target costing. In the traditional process, a product usually is defined by the marketing department and is then "thrown over the wall" to the engineering department, where technical specifications are set. When all work is concluded, process engineers execute final documents (Cooper and Slagmulder 1997).

Construction projects often suffer a similar fate; cost overruns and unsatisfactory customer value are common (Forbes and Ahmed 2011). TVD is a tool used by Lean Construction practitioners and is envisioned as a target costing adaptation for the construction industry (Macomber et al. 2007). TVD can profit from the early involvement of key stakeholders by the use of IPD processes. The TVD approach considers the construction industry as a complex system, including: (i) product definition, and (ii) design and construction stages. The goal is higher value-added delivery, using continuous improvement and waste reduction (Denerolle 2013). TVD research and practice have been carried out within the lean philosophy framework and rely on the benchmarking practices (Table 1).

It is important to mention that the way teams are traditionally organized is not always appropriate for TVD. TVD relies on IPD principles and they need to be considered in order for a TVD project to succeed. IPD is an integrated design process that engages the knowledge and expertise of each team member, seeking the best and most integrated design solutions (AIA 2007). In IPD, all the members involved with the project development work collaborate as a single team. This can be a challenge for some stakeholders (Zimina et al. 2012). Targets in TVD help avoid scope creep and compromising those elements, which the owner most values; issues commonly observed on traditionally delivered projects.

Table 1: TVD Benchmark (Adapted from Ballard, 2011)

Element	Description	Element	Description
1	With service providers, the customer develops and evaluates the project business case.	10	Team members discuss about the cost, schedule and quality implications of design alternatives.
2	The business case includes specification of an allowable cost. Financial constraints and limitations are specified.	11	Cost estimating and budgeting are done continuously through intimate collaboration.
3	The feasibility study involves all key members.	12	The Last Planner® system is used to coordinate the actions of team members
4	Feasibility is assessed through aligning ends, means and constraints	13	Targets are set as stretch goals to spur innovation.
5	The feasibility study produces a detailed budget and schedule aligned with scope and quality.	14	Target scope and cost are allocated to cross-functional TVD teams.
6	The customer is an active and permanent member of the project delivery team.	15	TVD teams update their cost estimates and basis of estimate (scope) frequently.
7	All team members understand the business case and stakeholder values.	16	The project cost estimate is updated frequently to reflect TVD team updates.
8	Some form of relational contract is used to align the interests	17	Co-location is strongly advised.
9	Cost and schedule targets cannot be exceeded, and only the customer can change target scope, quality, cost or schedule.		

RESEARCH METHOD

An exploratory single case study was adopted as a research method. The appropriateness of this method is related to theory development and expansion of the empirical field of knowledge (Yin 2010). Additionally, it could open new avenues for further research with a view to generalization.

The case described in this paper was carried out within a property developer in Brazil. The selected company develops properties for sale to upper- and middle-class households. The company has a set of 15 products classified into three categories: Family (entry, transition, and established), Commercial (offices, retail and companies headquarters) and Niche (second home and exclusive properties).

Interviews with property developer's staff were used as the main data collection tool. Company´s documents related to product development were also analyzed as a triangulation approach, as a means to increase the validity of results (Yin 2001).The interviewees include two product developers (with 5 and 12 years of experience) and one lead architect. The interviews aimed to understand the product development process, and then to diagnose the developer in relation to which TVD elements were already implemented, even if in a non-systematic or unconscious way. The 17 elements of the current TVD process (Table 1) were used to assess the adoption of TVD elements. The status of the adoption of the 17 elements was classified as: (i) Not Applied; (ii) Not Systematic or Partial Application; (iii) Applied but Changes are Needed[5] and (iv) Systematically Applied

Data analysis involved the development of a case study database, which included the interview transcripts and the documents collected during data gathering. Finally, a discussion on the appropriateness of the adoption of the TVD benchmark for the Brazilian real estate context is offered and new research questions are formulated. In this work, the research question is tightly scoped within the context of an existing theory, i.e. it relies on the TVD current benchmark and its already successful applications where clients build for their own use. The justification rests heavily on the ability of qualitative data to offer insight into complex social processes that quantitative data cannot easily reveal (Eisenhardt 2007).

EXPLORATORY CASE STUDY

There is a fierce competition in today's Brazilian real estate market, due to an economic situation where potential buyers are more selective and scarce, so supply is greater than demand. Besides, in that situation the property developer drives the product development, as opposed to users, who are the potential buyers of those products. Frequently, there is also little consideration about what constitutes the value proposition for them.

Evidence from non-structured interview with the product developer indicated that cost-cutting efforts were more common than trying to determine the value proposition for users or potential buyers. Therefore, there is little consideration on systematically determining what represents value for them (Oliva 2014). The value proposition of the potential buyer is mostly determined in relation to product's features that could be saleable. The final product consists of selling units, in which the time to launch to market is crucial, as the longer this period is, the greater the probability of loss of sales to competitors will be, and the greater the difficulty to reduce costs will be. Due to the real estate characteristics of intense competition between real estate market players, even considering the other benefits, the potential for improving their competitive advantages by adopting the TVD approach is among one of the most desirables.

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[5] In this case, although the principle is applied, its adoption occurs in a way that its benefits are not fully achieved according to the TVD theoretical framework.

The basic requirements of TVD elements and collaborative business practices are relatively new and are still not widely spread within the Brazilian construction industry. The following features describe the current scenario:

Highly fragmented design process development – the building company commonly outsources the design projects (architecture, MEP, structure, etc.) in a low collaborative work flow;

Time to launch new products in market is too long: up to 16-18 months. The company can lose potential buyers to the competition. A competitive advantage is, therefore, desired;

The property developer drives the product development. The end users' perceptions of added value has little consideration in a new product development;

Main suppliers rarely participate in the product development process or they start their relationship in a later development design phase.

Figure 1 shows the current product development process of property developer A (Dev. A). It is a sequential, linear and highly fragmented process from land acquisition to launch. The product development process covers 2 cycles: Land acquisition and Real estate development. The cycle of land acquisition lasts for 4 to 6 months. The cycle of Real estate development (from design to launch) lasts for 12 to 18 months.

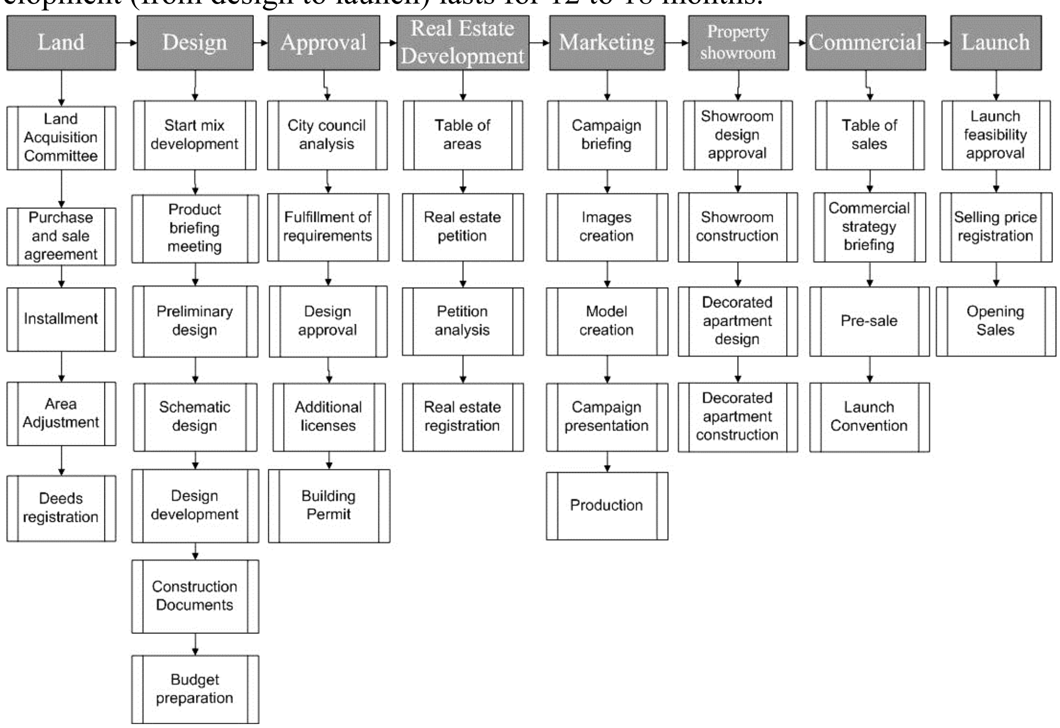

Figure 1: Product development process of Dev. A (Melo; 2015)

Figure 2 sums up the findings of the first stage data collection process, regarding how the TVD´s 17 elements (Table1) were classified in the product development process of the Dev. A i.e.: (i) Not Applied; (ii) Not Systematic or Partial Application; (iii) Applied but Changes are Needed and (iv) Systematically Applied.

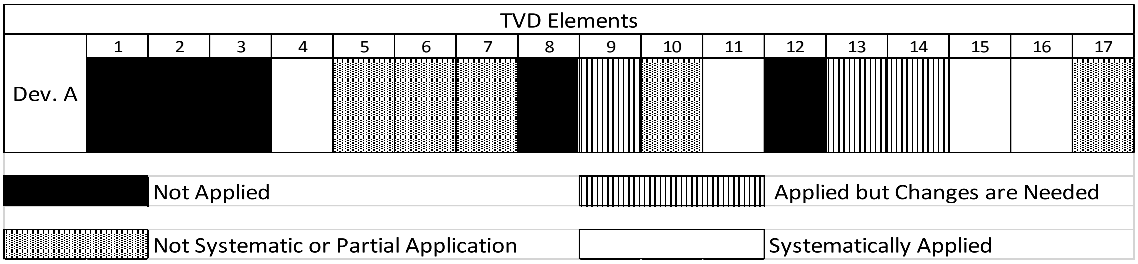

Figure 2: First stage data collection: TVD's 17 elements applied by Dev. A

TVD is influenced by IPD, which in turn depends on increasing levels of collaboration between the parties involved in the project in order to achieve its full potential. In consequence, in the second stage of the case study a TVD adoption based on evolutionary levels of collaboration was proposed (AIA 2007) (Table 2).

Table 2: Levels of Collaboration (AIA 2007)

Level of Collaboration	**Main Characteristics**
Level 3 – Required	Use of multiparty contracts, requiring participation of all agents involved in risk-sharing, joint decision-making and co-location for, providing a more collaborative environment.
Level 2 - Acquired	Use of some relational and incentive contracts in order to achieve higher collaboration levels. Better collaboration, incentives for better productivity, more active participation of the user, greater involvement in the decision-making
Level 1 – Typical	Collaboration is achieved in some levels without formal contract. Limited risk sharing and open-book policy

To better fit the real estate characteristics in Brazil, Oliva and Granja (2015) allocated TVD´s 17 elements into the three collaboration levels defined by AIA (2007). Building Information Modelling (BIM) and the Last Planner System were considered as catalysts of the TVD adoption. They are important tools for achieving full benefits in a TVD adoption, accelerating the process, but they were not considered mandatory.

For the second phase, the participants were interviewed in order to understand the company´s readiness to adopt TVD. According to their assessment, the elements were allocated into 3 levels of evolutive collaboration for the company (Figure 3). The 3 elements of TVD allocated on the Level 1 were regarded as easily implemented by the company's interviewees, according to its current product development practice. Level 2 and 3 "more challenging" TVD elements could be implemented over time as the process evolves into a full-fledged adoption of TVD.

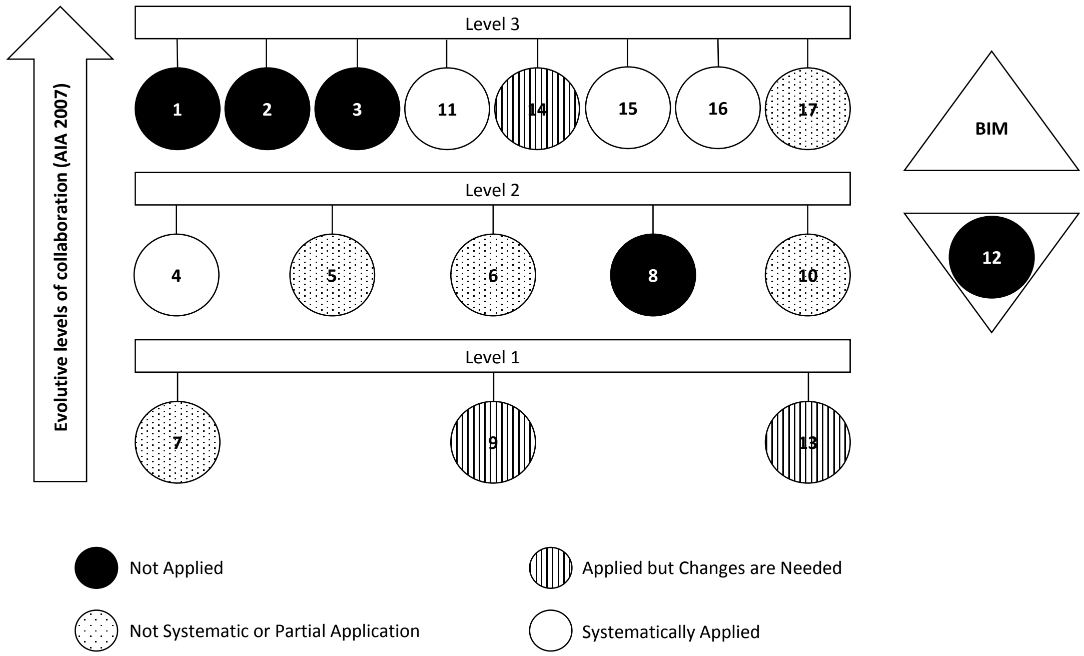

Figure 3: Allocation of the 17 TVD elements into 3 levels of evolutive collaboration (

KNOWLEDGE GAINED

After analyzing the data and the particularities of design process development in Brazil, some discussions about and research questions for TVD adoption could be raised. In the case study, one of the interviewees stated that "*what is value is pushed upon the potential buyer*", instead of being an input for design driven by those buyers. One of the interviewees said that "*the product's attributes must be sellable*" - an evidence of the pushed value, when it would be more interesting if the potential client could pull the design process. Therefore, the question one can raise here is: "How to determine value proposition of potential buyers to steer the design process?" Kowaltowski and Granja (2011) have already adopted a value assessment approach by end users of social housing projects, using a set of cards with various items that could represent value for those users. Among other tools for assessing the value proposition, this approach could be adapted for the peculiarities of consumers of real estate units for sale.

Another issue raised by the case study is that the real estate product development in Brazil occurs in a non-collaborative, adversarial environment. There is a lack of IPD awareness of TVD related concepts, besides a very long product development process. One of the interviewees pointed out: "*it lasts 16-18 months from inception to launch to market, and this can often represent the loss of potential buyers for competitors*". Therefore, one can address the following question: "How to promote more collaboration in a rather fragmented product development process, where IPD related concepts are still lacking?" Superior levels of the adoption the TVD elements in the Brazilian real estate sector could be reached according to the levels of collaboration posed in Figure 3. The rationale is flexible enough to address the current stage of collaboration of different companies and to begin an evolving adoption of the TVD elements.

CONCLUSIONS

This paper contributes to existing knowledge by discussing the adoption process of the current TVD process benchmark to the real estate market in Brazil and by deriving directions for future research. Departmentalized approaches or batch-and-queue product development identified in the selected developer might not be favourable to TVD implementation, due to its lack of integration. The current product development process often includes redesign activities and queues between departments, which could be a potential reason to convince developers to adopt TVD elements.

The method for the adoption of TVD elements progressively through the levels of collaboration (Figure 3) was not tested. The rationale behind it is flexible enough to address the current stage of collaboration of different real estate companies and to begin an evolving adoption of the TVD elements. Therefore, future research efforts could try to validate it and make adaptations for its use elsewhere, leading to generalizations.

The mindset of real estate property developers tends mainly to relate the TVD benefits to a potential approach to develop competitive advantage in a rather aggressive environment such as the real estate market. For this reason, revisiting TC's products' development original theory could bring additional insights for possible adaptions for TVD better suitability to this context. One such opportunity for strengthening the benefits of TVD adoption in Brazil could be adding targets for reducing time to market of products in this environment. Finally, TVD could also teach real estate developers to deliver products that arrive at a price that works for them as well as for their buyers.

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BENCHMARKING IN INTEGRATED DESIGN PROCESS: UW-ARCF CASE STUDY

Yong-Woo Kim[1], Rahman Azari[2], and Jeff Angeley[3]

ABSTRACT

Integrated Design (ID) process has been recognized as an integrated approach to design process and prevailed in sustainable high performance building design. Though prevailing assumption is that a more integrated design process yields better performance results, measurement of integration is a largely unexplored area of research which can help participants in the ID process assess their integrated performance. In a previous publication, the authors investigated the relationship between the level of integration in the ID process and project performances using data from 55 LEED projects in which ID was employed. In this paper, the database and the assessment framework are used as a benchmarking tool to assess the ID process of ARCF (Animal Research Care Facility) project at the University of Washington Seattle campus.

We expect that the research would contribute to the domain of ID process by providing an assessment tool to be used by project owners and service providers to evaluate their ID processes.

KEYWORDS

Integrated design; benchmarking; Sustainable High-Performance (SHP) building

INTRODUCTION

In recent years, the growth in Sustainable High-Performance (SHP) building development has increased significantly due to the industry’s rapid response to environmental challenges. In order to design a successful SHP building, Integrated Design (ID) process is applied (Azari and Kim 2015) which recognizes interdependency of various aspects of sustainability in a building, and their complex interactions over the complete life-cycle of the building (Azari and Kim 2015). In addition, ID process maximizes the SHP building’s performance in terms of cost, energy consumption, and sustainability (7Group and Reed 2009). The success of ID process depends on the early involvement of project stakeholders and implementation of extensive technical knowledge and systems-thinking during the design phase (Azari and Kim 2015).

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Azari and Kim (2015) created a systematic evaluation framework that was designed to assess the level of team integration in the Integrated Design Process of Sustainable High-Performance buildings. Azari and Kim proposed that with the increase in level of integration in the design process, the achievement of outcomes can also be improved (Azari and Kim 2015). Their evaluation framework was developed based on the Context, Input, Process, and Product (CIPP) evaluation model (Stufflebeam 2003) that is widely applied in the business and educational contexts. Their evaluation framework consists of four components, which include evaluation model, evaluation factors, evaluation items, and a measurement format. In addition, the existing framework was validated with a quantitative methodology that uses a survey with 79 survey responses. With this framework, Azari and Kim (2015) expect that owners and architects can use the tool to evaluate and diagnose the performance quality of the ID process in respect to SHP building projects.

Functioning as a performance measurement system, the evaluation framework also allows companies and organizations to conduct benchmarking in the area of ID process of SHP building projects. With benchmarking, companies will be able to identify key strengths and weaknesses, and to implement necessary improvement strategies. This paper aims to show a case of benchmarking on UW's ARCF (Animal Research and Care Facility) project using Azari and Kim (2015)'s proposed evaluation framework.

ID (INTEGRATED DESIGN) EVALUATION FRAMEWORK

Azari and Kim (2015) proposed an integration evaluation framework for the ID teams of SHP projects. Figure 1 illustrates this framework which consists of four major components: a) CIPP evaluation model/categories, b) 20 evaluation factors, and c) 65 evaluation items.

Evaluation Factors (20 factors)

The evaluation factors refer to macro-level areas which need to be evaluated, under each and all four categories of the CIPP model, in order to assess the integration level of the ID teams in SHP projects. 20 factors were identified through qualitative research (Azari and Kim 2015). 'Collaboration', as one of the evaluation factors, was a broad concept and was broken into seven sub-factors, as shown in Figure 1.

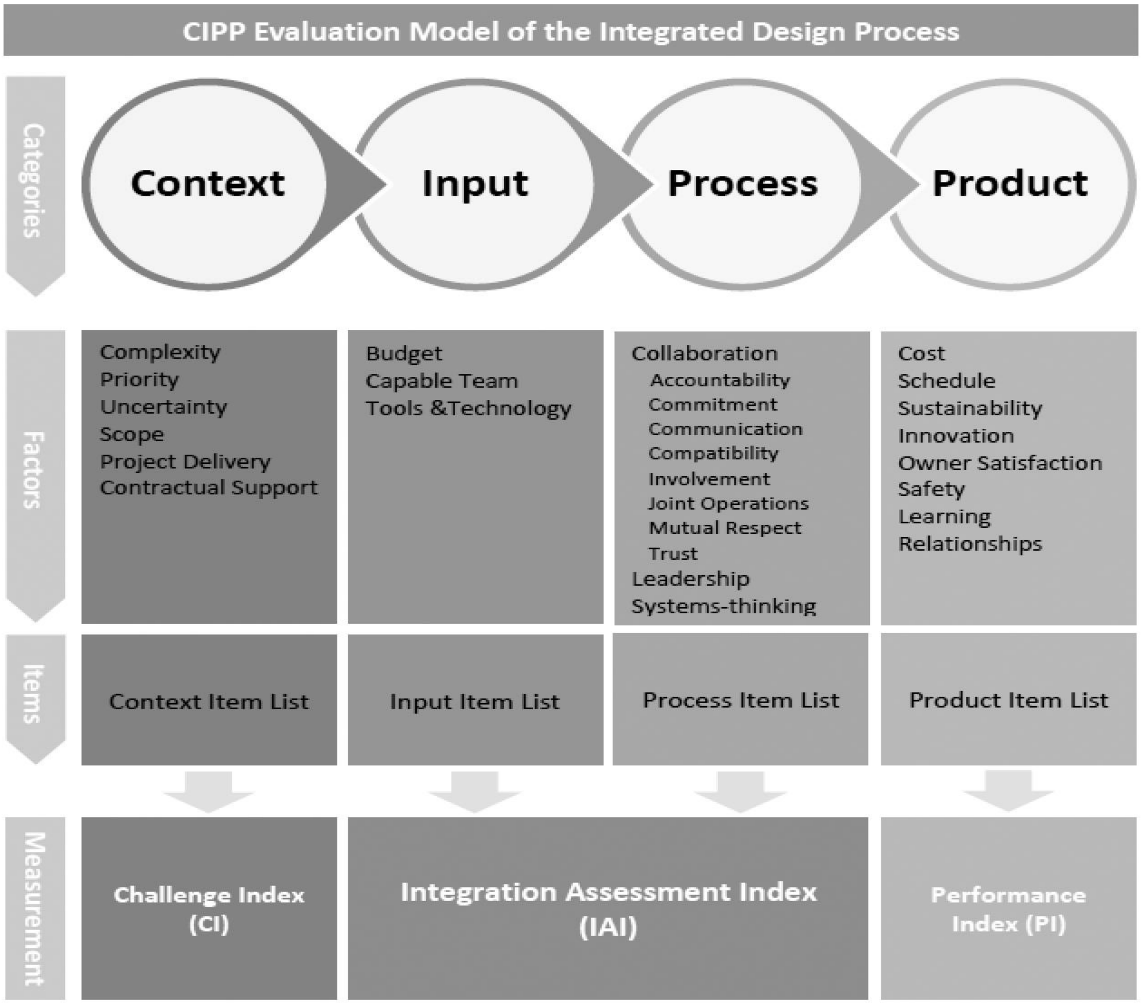

Figure 1. CIPP integration evaluation model for the ID teams of SHP projects (Azari and Kim 2015)

Evaluation Items (65 items)

To facilitate integration evaluation, evaluation factors were operationalized (i.e. specified) into 65 specific evaluation items – indicators - in order to provide tangible and measurable criteria for evaluation of the factors. These evaluation items were identified based on the interviews with industry experts as well as previous studies in the field. Some important issues considered in generating evaluation items included: reflection of the purpose, level of needed specificity or generality, clarity, validity, reliability, etc. (DeVellis 2003). The resultant final list of evaluation items included 65 items. Table 1 shows a random example of evaluation items that were specified to capture the presence of 'systems-thinking', as an evaluation factor, in the ID team environment.

Table 1. Four (4) evaluation items were specified to capture 'systems-thinking' (Azari and Kim 2015)

Systems-thinking	The ID team thoroughly discussed in the joint meetings the tradeoffs and synergies of the following major sustainability elements before making design decisions: (form and energy use, site potentials and energy use, site potentials and daylighting, site potentials and ventilation, daylighting and energy use, ventilation and energy use, etc.)
	The ID team thoroughly discussed in the joint meetings the impacts of design decisions across '*relevant disciplines'* before making design decisions.
	The ID team thoroughly discussed in the joint meetings the impacts of design decisions over the '*project lifecycle*' before making design decisions.
	The team as a whole is motivated to achieve sustainable design and followed opportunities for that through exploration and discussions rather than mere pursuit of green building rating systems.

Scoring

To use the proposed framework, the user will express his agreement with the evaluation item statements based on an equally weighted 5-point Likert scale in which the scores of 1, 2, 3, 4, and 5 reflects 'strongly disagree', 'disagree', 'neutral', 'agree' and 'strongly agree', respectively. Then, three simple indices aggregate the scores based on the equations 1 to 3: 1) Challenge Index (CI) represents challenges arising from the 'context' of a project; 2) Integration Assessment Index (IAI) represents the items in 'input' and 'process' evaluation categories which would indicate the level of integration maturity; and 3) Performance Index (PI) that represents the 'product' category. The following equations were used for building these indices:

Formula 1: $\mathrm{CI} = \sum \mathrm{S_c}$

Formula 2: $\mathrm{IAI} = \sum(\mathrm{S_i} + \mathrm{S_{ps}})$

Formula 3: $\mathrm{PI} = \sum \mathrm{S_{pt}}$

Where,

- CI, IAI, and PI refer to Challenge Index, Integration Assessment Index and Performance Index, respectively;
- S_c, S_i, S_{ps}, and S_{pt} refer to the scores assigned to evaluation items in the context, input, process, and product categories, respectively.

Using this measurement format, the minimum value for each index can be determined by using these formulas and assigning a score of 1, which represents 'strongly disagree', to all evaluation items in the category, or categories, corresponding to that index. Likewise, using a score of 5 (for 'strongly agree') results in the maximum values for CI, IAI, and PI. The performance of a given project on these indices would vary within the range between minimum and maximum values. To rate projects based on their performance on the three constructed indices, the ranges of indices were translated into multiple intervals shown in Table 2 (Azari and Kim 2015).

Table 2. CI, IAI and PI Indices and their Weight Ranges

Challenge Index (CI)		Integration Assessment Index (IAI)		Performance Index (PI)	
Extremely Challenging	29-37	Extremely Integrated	190-225	Extremely Successful	39-45
Moderately Challenging	20-28	Moderately Integrated	154-189	Moderately Successful	32-38
Somewhat Challenging	11-19	Somewhat Integrated	117-153	Somewhat Successful	23-31
Mildly challenging	2-10	Mildly Integrated	81-116	Mildly Successful	16-22
Not challenging	-7 to1	Fragmented	45-80	Unsuccessful	9-15

CASE DESCRIPTION: UW-ARCF PROJECT

The Animal Research and Care Facility (ARCF) is a two-level, 44,900 ASF, below grade animal research facility project on the University of Washington Seattle Campus. The project is intended to centralized and expand the University's animal research and care capacity for the next 10 years. Some of the program includes laboratories, procedure rooms, imaging facilities, cage, and equipment wash facilities; the project requires high flexibility in design. Due to the restriction of being a public project, the project proceeds with a GC/CM contract, however since the project is highly complex, an 'IPD-like' approach of team organization had been chosen.

Benchmarking Survey using IDEF (Integrated Design Evaluation Framework)

To obtain the data for qualitative benchmarking, survey was conducted as the main data collection method. The evaluation items and questionnaires based on the IDEF (Integrated Design Evaluation Framework) are used to assess the performance of the integrated design process. The survey was distributed to all project participants (24) who were involved in the design process through UW campus catalyst. Each project participant could log in and respond to each questionnaire through UW campus catalyst. 18 professionals participated in this survey; a 75% response rate.

Results

As discussed, the survey consists of three categories: context, process, and performance. This section addresses survey results in each section.

Context

The level of context reflects the level of uncertainty, challenges, and contractual structures that may affect the integrated design process. As shown in Table 4.1, ARCF scores 23.3 with benchmarking group averaged 24.1 (max score in this category is 40). ARCF is ranked in 43.89 percentile – which indicates ARCF is almost similar in terms of its context to projects in the existing database.

Table 3. Benchmarking Results: Context Level

Benchmarking Area: Context Level (out of 40)

	ARCF	Benchmarked Group		Percentile
		Average	St. Dev.	
CI	23.3	24.1	5.2	43.89%

Areas in Context Category

In the context category, the scope definition was scored "low" compared to projects in existing database as seen in Table 4. The project was scored only in 29 percentile. The question asked how you could rate the level of scope definition.

Table 4. Score of Scope Definition

Max = 5	ARCF	Benchmarked Group		Percentile
		Average	St. Dev.	
Scope Definition	2.63	3.04	0.74	28.98%

The research further investigated the responses by organizations: which might reveal different perspectives on the same issue. As shown in Table 5, all three stakeholders recognized and agreed that the project was not well defined initially.

Table 5. Score of Scope Definition by each Stakeholder

Max = 5	Group		
	Owner	Contractors	A/E
Scope Definition	2.5	2.25	2.33

Note: 5 = well defined

Process

The level of context reflects the level of integrated design process which includes the following ten factors: Accountability, Commitment, Communication, Compatibility, Involvement, Joint Operations, Mutual Respect, Trust, Leadership, and System-Thinking.

As shown in Table 6, the combined score of process category at ARCF is 164.73 out of 225. Compared to benchmarked projects, the level of integrated design process at ARCF is ranked in 73.31 percentile with average of 141.24. The score suggests that the level of integrated design process at ARCF is better than average of benchmarked group. The scores of each factor will be addressed in the next section with interview results.

Table 6. Benchmarking Results: Context Level

Benchmarking: Process / Integration Level (out of 225)

	ARCF	Benchmarked Group		Percentile
		Average	St. Dev.	
Process-Level	164.73	141.24	37.75	73.31%

Areas in Process Category

The area of mutual respect was scored in 32 percentile compared to projects in existing database as seen in Table 7. The questions asked to measure the level of mutual respect include:

- The team members are sympathetic towards other parties' situation.
- Project team members go beyond their obligations in meeting other parties' request.
- The team members feel valued by other team members.

Table 7 shows responses from each project stakeholder. The score of contractors and designers was lower than that of owners.

Table 7. Score of Mutual Respects by Stakeholders

Max - 5	ARCF	Benchmarked Group		Percentile
		Average	St. Dev.	
Mutual Respect	3.42	3.67	0.55	32.47%

Performance

The level of performance category reflects how well the project achieved project goals. Since the project just began its construction phase, only performances during design phase were evaluated. As shown in Table 8, the combined score of performance category at ARCF is 32.24 out of 40. Compared to benchmarked projects, the level of integrated design process at ARCH is ranked in 69.95 percentile with average of 28.13. The score suggests that the level of integrated design process at ARCF is better than average of benchmarked group. The scores of each factor will be addressed in the next section with interview results.

Table 8. Benchmarking Results: Performance Level

Benchmarking: Design Performance Level (out of 40)

	ARCF	Benchmarked Group		Percentile
		Average	St. Dev.	
Performance-Level	32.24	28.13	7.86	69.95%

Areas in Performance Category

The schedule performance was scored in 21 percentile compared to projects in existing database. All stakeholders agreed that design was significantly delayed.

DISCUSSION AND CONCLUSIONS

This paper shows a systematic benchmarking tool for evaluation of integration in the Integrated Design process. This dimension of contribution to knowledge is of special importance as previous literature (Xue, Shen, & Ren, 2010) highlights the lack of an effective framework to measure collaboration, an integration element, in construction industry. Functioning as a performance measurement system, the proposed evaluation framework of integrated design process allows project stakeholders to perform benchmarking in their integrated design process. With benchmarking, they will be able to identify key strengths and weaknesses as well as to develop necessary improvement strategies.

The research applied the evaluation framework of Integrated Design (ID) process to UW's ARCF (Animal Research and Care Facility) for benchmarking and performance analysis. The research used the survey results for conducting competitive benchmarking against the reference projects. The results showed that the project was highly integrated and expected to reach the goals. Although there were some areas for improvement, the project integration can be still operating effectively.

The benchmarking process is able to assist the project architect or owner in identifying key strengths and weakness in the area of project's integrated design process. Moreover, the evaluation tool can be used as a reference or guideline to steer a integrated design team's process.

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LEAN DESIGN IN BUILDING PROJECTS: GUIDING PRINCIPLES AND EXPLORATORY COLLECTION OF GOOD PRACTICES

Jéssica V. Franco[1] and Flávio A. Picchi[2]

ABSTRACT

In Construction, the application of lean thinking in design development comes as an innovation in the sector by bringing focus on what is waste and what is value.

In this context, the aim of this paper is to, first, identify which are the guiding principles for lean product development, by literature review in different industries; and, second, based on these structured principles, perform an exploratory collection of good practices in building design projects.

In order to identify the guiding principles a literature review was conducted and, after that, case studies were carried out in three Brazilian Construction and Architecture companies, plus one international Architecture company.

The guiding principles showed to be a good structured way of colleting lean design good practices; additionally, in the case studies it was detected if and how lean design principles are applied in the companies.

As a contribution, this work established structured lean product development guiding principles and gathered an exploratory collection of building design good practices.

For future work, the evolution of the guiding principles in a framework for application, the adaptation of some lean principles for building design and more studies to test the application of related practices in the sector are suggested.

KEYWORDS

lean product development, lean design, design management

INTRODUCTION

In Construction, the design development process has great influence on the quality and success of a Project. The application of lean thinking in design development comes as an innovation in the sector by bringing focus on what is waste and what is value.

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Several authors have established structured principles, practices and tools for a generic lean product development, having manufacture as reference, highlighting Womack et. al. (1990), Ward (2007), Morgan & Liker (2006) and Kennedy et. al. (2008).

In building design there are several studies that consider the application of some of these principles (Ballard & Zabelle 2000; Jorgensen, 2006; Reifi & Emmitt, 2013), for example: the use of lean tools and techniques to achieve value delivery, integration and waste reduction in the process. Additionally, Lean design management has been started in some building projects by now bringing good results (Lostuvali et al. 2012, Vinas 2014).

However, most studies in building design focus only on a few lean practices without considering the full application and all lean product development principles described in literature. According to Reifi et. al. (2013), although there are a certain number of studies that approach lean design related themes, it is still under debate in terms of what it is, and how to best implement it.

For this reason, the aim of this paper is to first identify which are the guiding principles for lean product development by literature review in different industries and, second, perform an exploratory collection of good practices based on these structured guiding principles.

It expects to establish a structured way for collecting lean design practices in building projects and, based on that, to present the findings extracted on the exploratory case studies.

METHOD

To identify the lean product development guiding principles, a literature review was conducted considering the main authors that have established principles for lean product development in different industries.

After that, case studies were carried out in three Brazilian Construction and Architecture companies, that do not openly apply lean design (Study I), plus an international Architecture company that declares to use lean design techniques (Study II).

For data collection, design managers and architects from the studied companies were interviewed and provided documents to illustrate the reported practices.

The research phases were: literature review, guiding principles proposition, questionnaire's preparation, case selection and characterization, information gathering, information analysis and conclusions.

LEAN PRODUCT DEVELOPMENT PRINCIPLES

KNOWLEDGE HIERARCHY AND TERMINOLOGY

To organize existing theoretical and practical knowledge, Koskela (1996) proposed a three layers pyramid that follows a hierarchical progression from high abstract to low abstract layers. Santos (1999) broke the third layer called *methodology* and proposed a pyramid including four layers, from top to bottom: concepts, principles, implementation approaches and tools/ techniques.

Based on that, in this paper the terms will adopt the follow definitions:

a) Concepts: abstraction or idealization of a topic (Koskela, 1996);

b) Principles: describe the pathway to transform existing reality through the basic idea set by a concept (Santos, 1999);
c) Practices: describe how to implement a principle;
d) Tools and Techniques: are designed to help the determination of specific answers to specific problems (Santos, 1999);
e) Methods: a combination of practices, tools and techniques that approach the same theme.

LEAN PRODUCT DEVELOPMENT GUIDING PRINCIPLES

Lean thinking was first applied on production process; however, eliminating waste in production is possible until a certain point when product and process engineering becomes a critical barrier (Morgan & Liker 2006).

Ward et al. (1995) presented the Toyota way of developing products and how delaying decisions was their second biggest paradox, followed by their production system. In that time, the authors already believed that innovation on product development would be as important as their revolutionary production system.

In the same way, Sobek et al. (1999) highlighted how Toyota's set-based design contributed with the extraordinary results that the company had in comparison with others.

On the theoretical basis about lean product development, some authors put their efforts on adapting and elaborating lean principles focused on this environment.

Womack et. al. (1990) firstly pointed some lean techniques applied to product development: Leadership, Teamwork, Communication and Simultaneous Development.

Ward (2007) described five main foundations about it: Focus on value; Entrepreneur System Designers (ESDs); Teams of Responsible Experts, Set-based concurrent engineering; Cadence, Pull and Flow.

Kennedy (2003) proposed a methodology for implementing lean product development highlighting the importance of leadership and workforce involvement and, later (Kennedy et. al. 2008), extracted five critical success factors adding cross project knowledge as one of them.

Morgan & Liker (2006) developed thirteen principles separated into three groups: process, skilled people, tools and techniques. These principles compiled practices that must be applied and aligned in order to achieve the results by a lean process.

Recently, Hoppmann et. al. (2011) elected eleven lean product development principles based on the themes addressed by the main authors (Womack et. al. 1990, Morgan & Liker 2006, Ward 2007, Kennedy 2003).

As one of the attempts of this paper, it was established which are the lean product development guiding principles. These principles, showed on Table 1, were based on Hoppmann et al (2011) with the addition of the principle *Focus on Value* and the merge of *Simultaneous Engineering* with *Set Based Design* in a single principle. At this time, structured principles were selected from literature that approach a generic lean product development, bearing in mind that these principles are able to be applied in all industries, including building design.

This principles list supported the information extraction in the case studies and the data organization of this paper.

Table 6 - Lean Product Development guiding principles

Principles	Womack et. al. 1990	Ward 2007	Morgan & Liker 2006	Kennedy et. al. 2008	Hoppmann et. al. 2011
1- Focus on value		X	x		
2- Strong leadership	X	X	x	x	x
3- Specialist Team		X	x	x	x
4- Workload levelling			x		x
5- Responsibility-based planning and control		X	x	x	x
6- Cross-project knowledge transfer			x	x	x
7- Set based design	x	X	x	x	x
8- Supplier integration			x		x
9- Product variety management			x		x
10- Rapid prototyping, simulation and testing					x
11 -Process standardization		X	x	x	x

LEAN DESIGN IN BUILDING PROJECTS

In Construction, the discussion about lean application on product development achieves the design management field of work, for this reason it is called "lean design" when it concerns building projects.

Koskela et al.(1997), Tzortzopoulos & Formoso (1999), Ballard & Zabelle (2000) started the discussion considering the application of some lean practices in building design such as: Last Planner, reducing activities that do not add value, reducing process variability, reducing cycle time, multidisciplinary teams and simultaneous engineering.

More recent studies bring a wider approach. Jorgensen & Emmitt (2009) define that lean design applies a system to generate value and eliminate/reduce waste in building design; adopts customer's voice to define what is value; approaches design management with focus on process and flow; understands design activities through three concepts: change, flow and value generation; manages time pulled by client's needs;

From lean design management literature review, Reifi & Emmitt (2013) highlight four dominant themes related to the reduction of waste and the enhancement of value: briefing and client interaction, value and value stream mapping, lean culture and assembling the team and information flow.

The importance of design briefing was highlighted by other authors as well. According to Reifi et al. (2013) the brief plays a vital role in presenting and communicating client requirements to the design and construction teams. By the fact that lean design processes is still under discussion, design brief can assume an important role in articulating declared and non-declared client's requirements and values and in defining how it must be delivered.

Another theme discussed in literature is how design workshops can contribute to lean design implementation (Thyssen et al. 2008; Emmitt et al. 2004). The workshops can occur several times and have different goals each time contributing to value identification, simultaneous development, team integration and process standardization, becoming an essential technique to add value in design process.

Regarding value adding, Target Value Design (TVD), a technique first developed on industry environment as Target Costing, it is being applied in Construction sector by including cost as a design criterion, seeking waste reduction and value generation. (Ballard 2006; Pennanen et al. 2010; Ballard 2011).

Team integration, earlier supplier involvement and multiple alternatives development are addressed by several authors (Ballard & Zabelle 2000; Jorgensen 2006; Reifi & Emmitt 2013; Emmitt et al. 2004; Thyssen et al. 2008; Ballard 2011) and define a key point for lean design: Set-based concurrent engineering (Womack et al., 1990; Morgan & Liker, 2006, Ward, 2007).

For achieving a lean design process, Integrated Project Delivery (IPD) as a delivery method may be crucial. IPD is when the owner has elected to sign a multi-party contract with the prime designer, contractor and/or other key members of the project team (AIA, 2010). The adoption of this method is currently been pushed by waste and lack of productivity, technological evolution (software) and owner demand for value which are all lean concepts, thus, it is a method that promotes collaboration and integration between members aiming to deliver product with higher value adding.

Moreover, technology also can support the application of lean concepts since there is a huge synergy between BIM technology and lean, once the use of BIM can enhance model checking and simulation methods enabling the purchaser to compare offers and construction alternatives (Breit et. al. 2010; Sacks et. al 2009)

Lean design management has been started in some building projects by now. In Cathedral Hill Hospital, Lostuvali et al. (2012) compared and contrasted their lean initiatives with the principles proposed by Morgan & Liker and conclude that most principles have been implemented to some extent, and a few still need to be worked on.

In the same way, Vinas (2014) described some exceptional results that a lean design development brought in Akron´s Children´s Hospital project including area reduction with higher flexibility in rooms.

EXPLORATORY COLLECTION OF GOOD PRACTICES

After proposing the guiding principles list described previously, two case studies were carried out based on this list for practices collection.

All studied companies deal with projects that have a certain grade of complexity based on its size, technical requirements and management issues. Since lean product development emerged in a complex environment (automotive industry), it is believed that its application in complex projects might bring more relevant results than in simple ones.

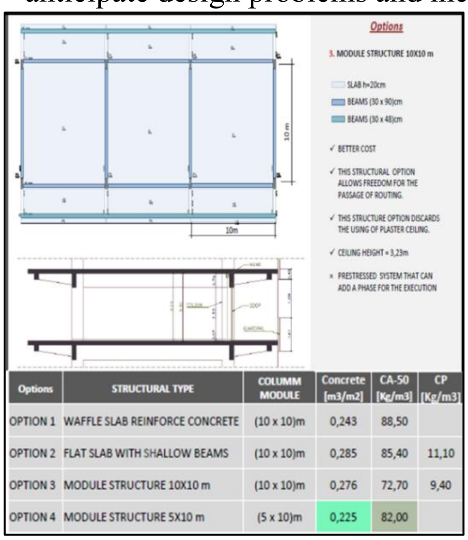
CASE STUDY I – CURRENT PRACTICES IN THREE BRAZILIAN COMPANIES

Case study I was carried out in three Brazilian companies: a Construction Company and two Architecture Companies. These companies act in national projects and do not openly apply lean design techniques; however, possibly there are already some practices aligned to lean design principles.

To exemplify the mentioned practices, interviewed professionals provided documents about two main Projects: Project B, a 100.000 sqm shopping mall; and Project C, a 38.000 sqm Institutional Building. Furthermore, they provided information about corporative processes as well.

The reported practices are detailed in Table 2, from them, the following aspects could be highlighted:

- Value Engineering studies to evaluate systems and design alternatives (Figure 5), which is a tool that is closely connected with TVD and also can support set based design;
- A collection of design indicators that keeps in the company the acquired knowledge in the projects, making easier alternative analysis and design decisions;
- Use of BIM technology for design coordination, planning and quantities' extraction (Figure 6) promoting design simulation and testing prior to construction in order to anticipate design problems and inconsistences.



Options	STRUCTURAL TYPE	COLUMM MODULE	Concrete [m3/m2]	CA-50 [Kg/m3]	CP [Kg/m3]
OPTION 1	WAFFLE SLAB REINFORCE CONCRETE	(10 x 10)m	0,243	88,50	
OPTION 2	FLAT SLAB WITH SHALLOW BEAMS	(10 x 10)m	0,285	85,40	11,10
OPTION 3	MODULE STRUCTURE 10X10 m	(10 x 10)m	0,276	72,70	9,40
OPTION 4	MODULE STRUCTURE 5X10 m	(5 x 10)m	0,225	82,00	

Figure 5: VE study (Case Study I)

Figure 6: BIM coordination model x Site picture (Case Study I)

CASE STUDY II – LEAN DESIGN PRACTITIONER COMPANY

Case study II has been carried out in an international Architecture Company that declares to practice lean design techniques in their projects and it has been an important source of lean practices, tools and techniques. This company acts worldwide having offices in eight different countries and provides architecture services for several kinds of buildings.

The interviewed professional provided some documents to exemplify their lean practices and describe some of them during the interview. The reported lean practices are detailed in Table 2; the following aspects could be highlighted from them:

- *Gemba* walk to understand client's operation and by that improve the requirement and value identification;
- Technical specialist teams to support design. The interviewed described that in Hospital projects they have a group of doctors and nurses for design review, practice that inputs in design the user's needs and functional improvement ;
- Pull planning workshops based on client's milestones to define delivery dates and deliverables. This practice is fully aligned with lean responsibility based planning and control for aligning the project information and for having the project team seeking the same goals;
- IPD as a delivery method including specific metric goals in contractual clauses for designers, TVD studies, supplier and constructor integration;
- The use of mock-ups, built in cheap materials, to test day-by-day procedures and design alternatives. The interviewed exemplified this practice describing a full nursery department of a Hospital project that was built in full scale for doctor, nurses, users, patients and designers to test it.

GOOD PRACTICES FOR LEAN DESIGN IMPLEMENTATION

Based on the results from the case studies, the good practices were organized on Table 2.

Table 7 – Good practices found in the Case Studies

Principle	Good practices	Tools and techniques
1- Focus on value	• Identify value and client requirements (I) (II) • Establish metrics (II) • Establish a target cost (II)	• Cost spreadsheets that distributes a global cost into a ABC analysis to develop a target for each system design (I) • VE studies (I) (II) • Metric goals in contracts. (II) • *Gemba* walk. (II) • Design workshops. (II) • Detailed briefing.(II)
2- Strong leadership	• Select a leader to merge client needs into the design process (II)	

Table 2 – Good practices found in the Case Studies (cont.)

Principle	Good practices	Tools and techniques

3- Specialist Team	• Work with specialists on briefing definition (I) • Form multidisciplinary teams to contribute in technical discussions (I) • Form a team of customers to review the design and operation of the building (II)	
4- Workload levelling	• Develop professionals that have flexibility to work in different types of projects and departments. (I) • Share human resources with other company units and departments (II)	• Software to accurate the spent hours in a Project. (I) • Technology for remote working. (II)
5- Responsibility-based planning and control	• Planning pulled by client's demands (I) (II)	• Pull planning workshops (II)
6- Cross-project knowledge transfer	• Keep design indicators (I) • Promote lessons learned events (I) • Have a design database (II)	• Indicator's spreadsheet (I) • Design search tool (II)
7- Set based design	• Seek the early involvement of consultants, suppliers and builders (I) (II) • Develop more than one design option for client's appreciation. (II)	
8- Supplier integration	• Challenge suppliers on developing solutions to achieve a target cost (I) • Promote design-build and IPD contracts (II)	
9- Product variety management	(No practices were found aligned to this principle)	
10- Rapid prototyping, simulation and testing	• Use BIM technology for planning simulation, coordination and quantities extraction (I) • Build mockups to help the design development process (II) • Simulate design through software to test the design functionality (II) • Test mockups with day by day procedures (II)	• BIM software (I) • Rapid prototyping (II) • Mockups (II) • Simulation software (II)
11 -Process standardization	(No practices were found aligned to this principle)	

Source: (I) Case Study I/ (II) Case Study II

CONCLUSIONS

The guiding principles enabled a good structured way of colleting lean design good practices, making easier the analysis and showing to be a good tool for data collection in future works.

The exploratory studies showed that some principles are being applied in the studied companies, however, low relevant or none practices were found about principles 2, 9 and 11. Moreover, the case studies brought a collection of good practices that detailed ways for applying some lean product development principles in building projects.

As a contribution, this work established structured lean product development guiding principles and gathered a collection of building design good practices detected in three Brazilian companies and one international company.

For future work, an evolution of the guiding principles in a framework for application, an adaptation of some lean principles for building design and more studies to test the application of related practices in the sector are suggested.

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VSM FOR IMPROVING THE CERTIFICATE OF OCCUPANCY PROCESS IN REAL ESTATE PROJECTS – A CHILEAN CASE STUDY

Andrés Covarrubias[1], Claudio Mourgues[2], and Paz Arroyo[3]

ABSTRACT

Obtaining a Certificate of Occupancy (CO) for real estate projects in Chile is a bureaucratic and confusing process, which often causes delays in the final reception of projects, postponing the occupation by future owners, and impacting the financial flow of developers. This research aims to reduce the duration of the city´s CO process for housing projects in Chile. The research questions are: (1) what are the most relevant inefficiencies in the CO process? (2) What improvement strategies can be used to reduce its duration? (3) Can lean methods be used to reduce this duration? The research method is based on 3 stages: (1) conduct surveys to practitioners involved on the CO process of Chilean housing projects to collect the current inefficiencies and potential improvement strategies, (2) develop a current and future state Value Stream Mapping (VSM) considering the survey information, and (3) implement the future state in a case study through action research. This research´s first contribution to knowledge is a list of inefficiencies and improvement strategies related to the CO in Chilean housing projects. The second contribution is to provide evidence that VSM can be successfully used to reduce the duration of this process in housing projects. The study is limited to housing industry under the Chilean regulatory framework. However, the authors believe that similar results can be obtained in other types of projects dealing with administrative processes such as permitting, and other city and regulatory agency approvals.

KEYWORDS

VSM, Value Stream Mapping, Project Management, Reception Process, Certificate of Occupancy, Real Estate Projects, LEAN Management, LEAN Project Delivery.

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INTRODUCTION

The Certificate of Occupancy (CO) corresponds to a certificate or approving resolution issued by the building department that certifies that the work carried out is true to the building permit granted and therefore has faithfully complied with the law, applicable building codes, as well as the General and Local Ordinances. This occurs after a slow and bureaucratic process of reviewing records, documentation and visiting the site. Once the documentation has been approved and the site visit carried out, the architect or professional reviewer from the building department approves the project and then the rights can be paid and the approving resolution signed. The certificate allows the construction or building to be inhabited or used as was previously determined. A considerable delay in this process negatively impacts the profitability of a project as well as a company's cash flow, which, in the worst-case scenario, can lead to bankruptcy. In less serious cases, delays in handing over properties to clients may result in fines or the market's loss of trust in the real estate company. As a result, there is an important opportunity to use Lean tools to improve this final process of obtaining the CO. Koskela (1992) considers that efforts should be made to eliminate or reduce activities that do not add value, to then move on to improve the activities that do add value.

An important methodology for these efforts is Value Stream Mapping (VSM), which has been widely used to identify opportunities for improvement in the construction industry. This study applies VSM to construction projects' administrative processes, as opposed to the majority of applications that center on the productive processes of design and construction. This tool has been adapted, evolving to more complex characteristics (Braglia et al. 2006; Duggan 2002), with more random demands, number of processes, types of processes and motives that make the flow much more complex and complicated to analyze and diagram. This improvement is fundamental in the Chilean construction industry, as the process to obtain the CO is slow and bureaucratic, but above all it is unsystematic and uncontrolled; negatively impacting the economic viability of projects as well as the trustworthiness and image of the real estate company.

This paper also presents a case study where the improvement strategies identified using VSM are applied. The case study included part of the improvement plan, for the sake of time, but shows the impact on reducing delays in the first stage of the certification process.

LITERATURE REVIEW

Obtaining a CO is a relevant issue in many countries where they have to deal with bureaucracy and potential delays. Some studies have looked at the process of obtaining CO, such as Daramola and Aina (2004) in Nigeria and Rutakyamirwa et al. (2002) in Tanzania. Both studies looked at improving the process of obtaining CO, but they present cultural differences.

Several studies have applied VSM to improve construction processes, both onsite and offsite (Bulhões et al. 2011; Fontanini et al. 2008; Moghadam and Al-hussein 2013; Pasqualini and Zawislak 2005). Some studies have focused on the design process such as Lima and Rolim (2010), which applied VSM for architectural executive design in a governmental organization, and Leite and Barros Neto (2013), which applied VSM for Housing Design. However, few studies demonstrate the implementation of lean methods, including VSM, for improving administrative processes in construction such as obtaining CO, building permits, or other types of certifications. Alarcon et al. (2011) demonstrate the implementation of lean tools and methods in the permitting process for the Castro Valley Hospital in California, the research shows how the integrated team worked hand-in-hand with representatives of the state permitting agency to develop strategies and work methods to implement a new option called the Phased Plan Review, where the team and the agency could pursue in unison to result in permitting for construction of this healthcare facility. The paper mentions the use of visualization strategies, but does not mention the use of VSM. Alves et al. (2016) demonstrate the use of several lean strategies for managing submittals and requests for information (RFIs), and Pasadena et al. (2014) implements lean strategies for submittals, this study also points out the lack of transparency in administrative processes, such as unknown durations and lack of indicators to manage processes. In Chile, one previous study has applied VSM to the process of project evaluation by the social Chilean housing agency (Yuraszeck, 2007).

This research is based on the adaptation of the VSM methodology applied to the field of administration (Tapping and Shuker 2002). It is based on a study of real cases of a company in the industry whose objective is to define the type indicators with which the present state of VSM to improve the process of obtaining a CO will be modeled.

METHODOLOGY

The research is structured in 3 stages (Figure 1).

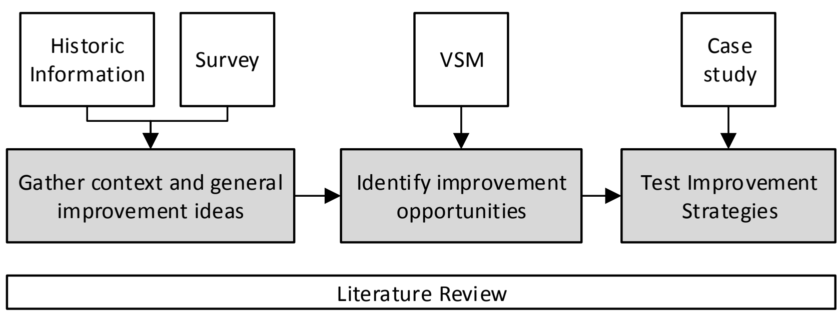

Figure 1. Research methodology

1. Gather context and general improvement ideas: This stage included reviewing the historic information of 16 projects from a real estate developer to identify the main indicators, actors and activities in the process of obtaining the CO. This contextual information guided the design and application of a survey to capture the perception of construction professionals regarding the process being studied and potential ideas for improvement.

2. Identify improvement opportunities: The results obtained in the survey helped to create VSM diagrams of the current and future state of the process to obtain the CO. The future state presented a set of improvement strategies.

3. Test improvement strategies: The researchers used a case study to test the identified improvement strategies. The case study is a 10-story housing and commercial building, located in the downtown area. Due to time limitations and specific characteristics of the project, not all strategies could be implemented.

The following sections detail the application and results of the survey, the VSM and the case study.

SURVEY

The survey included 3 sections: (1) context variables; (2) current situation from a market standpoint, which is divided into 2 parts, the current situation and alternative solutions; and (3) improvement opportunities, which is also divided into two, opportunities for improvement and obstacles.

The survey was carried out using an online form, with 3 questions regarding context and 15 on content, open-ended and multiple-choice. Distribution was over electronic mail and 66 universal responses were received from a multidisciplinary public from a wide range of job titles. Of the responses, 33.3% correspond to real estate companies, 22.7% to construction companies, 30.4% to architecture studios and independent architects, and the remainder from public bodies and companies that offer products and services for architecture and project development. The main results were:

- Important delays in the process exist, 54.6% of the companies claim to comply with their deadlines between 50% and 90% of the time. At the same time, 56.1% determine that the main delays fluctuate between 2 and 3 months.
- Delays are related to difficulties with public processes but internal management is also responsible. 68.2% of the people surveyed said that the delays can be attributed in a 10-25% to the company and in a 75-90% to the building department of the local government (municipality).
- Large public organizations are those that generate the most issues. 58 surveys marked this answer, with an 87.9%.
- The process is planned but standardization is missing during follow-up. 36.4% state that they always use planning tools, versus 19.7% who state they never use them for these processes.
- These delays affect profitability.
- Companies in general believe they can reduce the time it takes to receive the CO.
- Respondents reported opportunities to improve and willingness to change, but also barriers that make implementation difficult. 48.5% of the respondents think that definitively there is room for improvement; as opposed to the 12.1% who think that the process is complex and that it cannot be improved.
- Respondents identified improvement ideas but the know-how to implement them is missing. 47% are completely willing to change the way the process is carried out, 15.2% in large projects, whereas 6.1% say they are not willing and 15.2% say no but perhaps with concrete proposals for improvement they would be willing.

VSM FOR THE CO PROCESS

VSM allows graphically organize the interactions between the tasks of a process. Before beginning a Lean Manufacturing process it is necessary to map out the current state, showing the flow of processes, input and information. In their book *Lean Thinking*, Womack and Jones (1996) explain that modeling comes after surveying and graphically expressing all the actions that happen in a process. This process, in the VSM framework, is called flow and will be realized based on a family of processes.

The modeling process requires a series of 7 steps to be correctly applied: (1) define the process families involved in the product development. These process families establish the parts of the process, the sequential order and the characteristics of each box. Next begins (2) the timing of the diagram, defining the relevant indicators to measure. We used a survey of actual data on a timeline that considers the overall process, including the times between the different stages and within each task the time of the cycle, projected time, number of cycles for each activity, person responsible and number of indispensable people who participate in the task. This research considered it fundamental to include the industry's perception and opinion in detecting problems and applying improvements, so as to have real input when analyzing and creating the future model. The opinion was gathered through a perception survey. With all of the aforementioned and the designed data, we proceed with (3) modeling the current state. This current state is modeled based on the adaptation of the application tables to the specific requirements of measuring tasks of an administrative process towards a production process. This table establishes the tasks of the process and analyzes them through a value window. Then a condition is assigned to it (transformation, transport, control, wait). This condition will help the researcher to develop a reorganization of the tasks, according to the same table, for the future proposal.

Taking the diagram of the current state as the starting point, the researcher carried out an (4) analysis, using once again the value window to detect opportunities for improvement, but incorporating the responses obtained in the perception survey. This resulted not only in problems in timings and process order, but also in the planning. The planning problems included the way of carrying out the planning, responsibilities, fulfillment of commitments and overall monitoring of deadlines and process steps, as well as clarity with respect to the requirements to carry out the steps in the required time. This survey also showed results regarding opportunities for improvement. The analysis generated a series of changes in the order and structure of how tasks are fulfilled, but also in the way of establishing commitments and managing the process. These preliminarily conclusions were then validated through personal interviews with two on-site building managers.

(5) Using this procedure, a diagram of the future state was designed using the researcher's experience, technical knowledge from the onsite teams, survey responses and the current state analysis. Once the future state model was developed, we gave way to the (6) opportunity proposal. A set of tables and a checklist were developed as a proposal for planning and monitoring. Lastly the process gave way to the (7) improvement implementation. This is not a simple or quick step, as it involves changes from the start of the project, the signing of the contracts and the initial planning. It also involves changes in the culture on a company level and for each of the individuals that participate in the process.

From the improvement opportunities analysis, the preliminary conclusions were:

- Rearrangement of the tasks, depending on the deadlines involved.
- Redefinition of the timeline that the process considers.
- Attach the commitments and the certificates required for the process to the contract.
- Plan ahead of time all the actions that take longer in the cycle.
- Parallelize or overlap tasks in the process.
- Designate a process manager in the real estate company who accounts for the site manager and who follows the checklist, commitment table and deadlines.

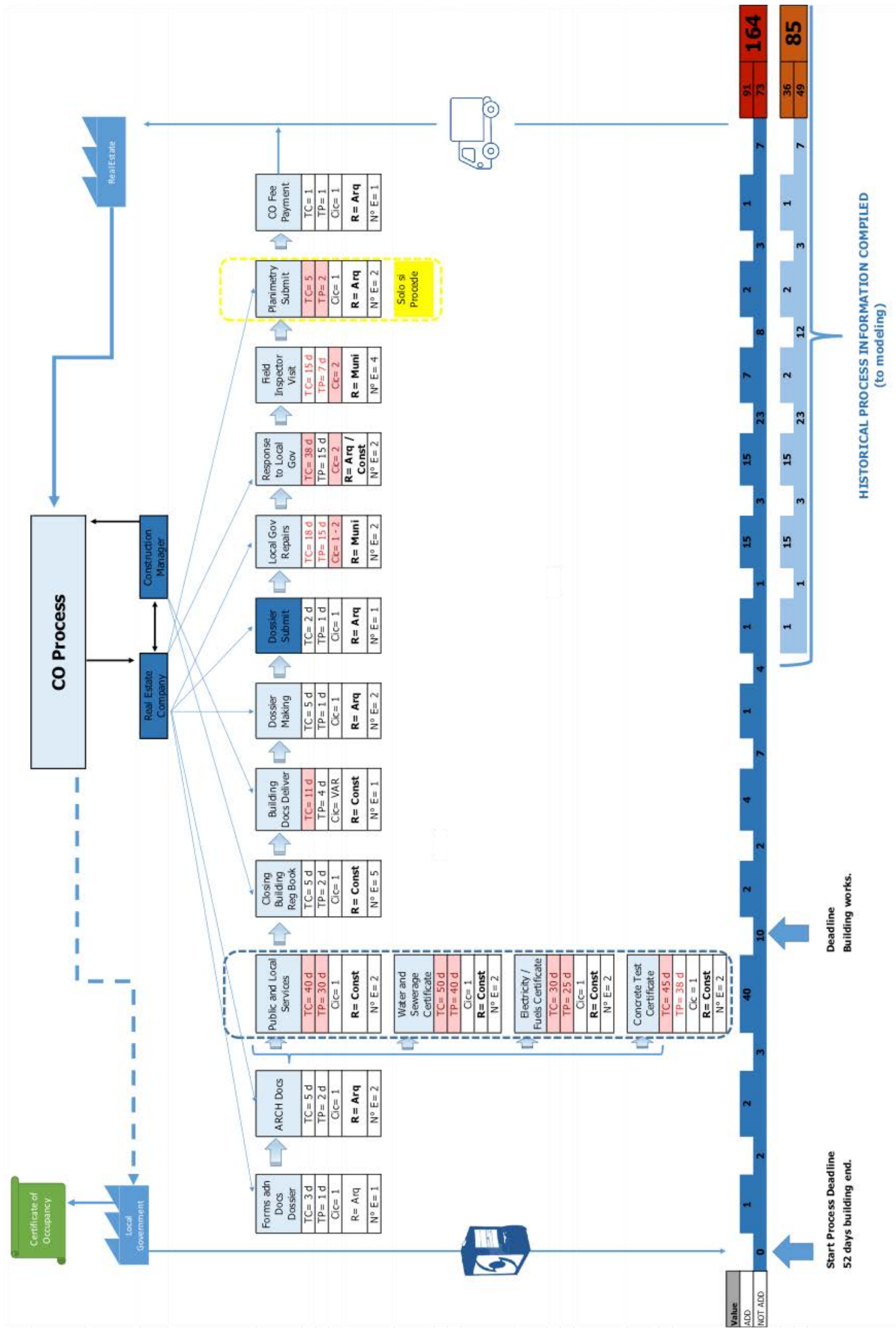

Figure 2. Current state, VSM diagram

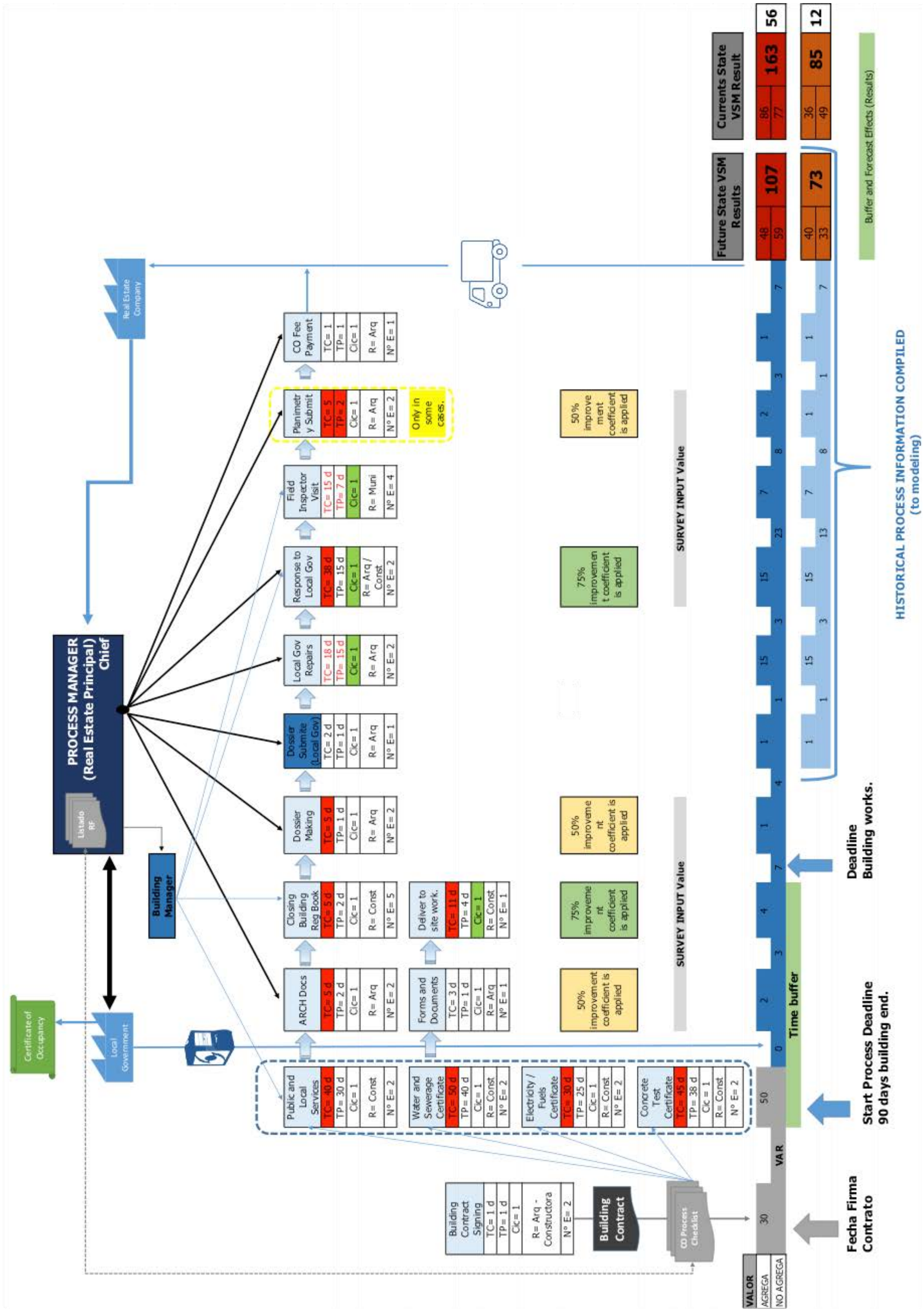

Figure 3. Future state, VSM diagram

With respect to the information analysis, the global process was improved in 75 days, reducing the duration from 163 to 88, considering from the beginning of the reception process to obtaining the CO. From this improvement, a subset is in the internal processing of the municipality's building department, which was reduced 12 days, reducing its duration from 85 to 73. All of these are theoretical results that reflect the VSM modeling and its considerations. The following section describes a partial application in a case study where important actual improvements with respect to timings were observed.

CASE STUDY

The initial review and compilation of historical information made it possible to determine real timeframes for the company's projects. The compilation of historical information was carried out over 16 projects of various sizes in 5 counties around the country. Information relative to the times from the date the file was entered, observation date, response time, approval time and time the CO was granted was compiled. The results were the following:

- Time to review background information: Minimum 5 days, Maximum 48 days, average 18.25 days.
- Time to respond to observations: Minimum 8, Maximum 72, Average 38 days.
- Observation cycles/Answer: Minimum 1, Maximum 3, Average 1.4.
- Approval time from the response: Minimum 2, Maximum 34, Average 23 days.
- Average 30 days to obtain the CO.
- Total: Minimum 4 days, Maximum 164, Average 79.25 days.

The improvement opportunities depicted in the proposed future state (previous section) were applied to the CO process of a mixed-use (residential, offices and commercial) 10-story building located in Los Andes county in the Valparaíso Region. Due to time restraints, the implementation did not consider all the recommendations identified with the application of VSM, however it included those concerning the formalities for receiving the CO. In this case, the list of certificates was sent to the construction company 3 months before beginning the process so as to speed up the timeframe considered in this process. The list consisted of a total of 36 certificates on behalf of the construction company and 16 for the real estate company. The results of the case study are the following:

- The project was submitted practically complete, with a total of 49 documents and certificates.
- Three visits from the field inspector carried out
- The entire process took 44 days where the historical information review shows an average of 79.25 days.

To obtain these results, the methodology was mainly applied through a process manager from the real estate company who coordinated the process, just as the improvement model proposes. A checklist was also used, but not in the contract stage, so more anticipations could have been foreseen. This specific case had an important delay in the sanitary and elevators certifications. The checklist was applied in December, two months before the programmed final reception. This application, before and during the CO process was a required instrument for the process order and planning as it established commitments from the first day of the process. Using this tool, the internal processes at the municipality's building department were effectively reduced.

CONCLUSIONS

The results of the research show that the process of obtaining the CO in Chile is inefficient and difficult, and that adapting the VSM methodology, from the productive to the administrative processes, is a path worth developing.

It can therefore be interpreted that in the case of real estate construction and management in the Chilean market there is a debt in the Lean Philosophy with respect to the administrative processes. The philosophy has been largely applied to the productive actions on site but its application is lacking for administrative tasks, meaning all the value that is added to the productive process is lost as the administrative process is not managed efficiently. The trend should be to support this vision for all parts of the process, incorporating a Lean contract that establishes shared responsibilities based on the final process checklist to then evolve into a follow-up commitment table. The Chilean market has evolved and is open to the possibility of implementing improvements; it is simply lacking the know-how to do so and thus is facing certain roadblocks to begin to innovate in these processes.

The increase in real estate development in the Chilean market makes it an urgent matter to improve the aforementioned processes. This research works specifically on the process to obtain the CO, but it is comparable to blueprints, building permits, co-ownership permits, among other municipality-managed processes and those managed by companies with a highly complex and bureaucratic internal processes. As this study shows, the theoretical analysis reduces the timelines by reorganizing the flow, reassigning responsibilities and using tools and inputs that support the process. It is also clear that this theoretical application can be used in practice to improve processing times, as it was shown by the case study.

It is evident therefore, that VSM can be used to evaluate administrative processes through small variations in the methodology. In this study, the VSM was applied by analyzing the current state map with the responses from the market. The application was validated by teams on site, but a considerable improvement could be applied if the situation was considered in its early modeling stages with feedback from more direct stakeholders. It can also be concluded that the VSM diagram is applied once, but the application of the improvement that result from the VSM should be complemented with LEAN planning tools like Last Planner, and the actions must be committed to from the beginning through a Relational Contract, for example.

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DEVELOPMENT AND TESTING OF A LEAN SIMULATION TO ILLUSTRATE KEY PRINCIPLES OF TARGET VALUE DESIGN: A FIRST RUN STUDY

Zofia K. Rybkowski,[1] Manish B. Munankami,[2] Mardelle M. Shepley,[3] and Jose L. Fernández-Solis[4]

ABSTRACT

Target Value Design (TVD) is increasingly being used for Lean-Integrated Project Delivery processes—especially in the healthcare facility sector. However, the basic principles of TVD take time to comprehend and can seem daunting when implemented for the first time on actual projects. The QUESTION this research sought to address is: Can basic principles of TVD be effectively taught via a relatively simple and brief simulation? The PURPOSE of this research was to develop and test a new simulation that would clearly illustrate basic principles of TVD. The RESEARCH METHOD used for this paper was the iterative development and testing a simplified simulation that modified and extended the "marshmallow challenge" game developed by Peter Skillman. The TVD simulation was tested by construction science students and design professionals in the US and Nepal. FINDINGS suggested the simulation offers an effective way to convey basic TVD principles such as Estimated Cost, Market Cost, Allowable Cost, and Target Cost, and designing to these parameters. The research had some LIMITATIONS, namely that it primarily addressed functional issues as criteria for design success and did not engage all aspects of TVD processes commonly used, such as A3 development, set-based design, or decision-making using *Choosing by Advantages*. However, the IMPLICATIONS and VALUE of this work are that the simulation appears to offer a simple, enjoyable, and effective way to introduce basic TVD principles and their impact to stakeholders who are engaging in the practice for the first time.

KEYWORDS: Lean Simulation; Target Value Design; target cost; Integrated Project Delivery; Marshmallow TVD Simulation

INTRODUCTION

Capital projects are expensive. To make them more affordable, Target Value Design exercises have been incorporated into Lean-Integrated Project Delivery processes during the past decade. The St. Olaf Field House served as a pilot project in target costing (Ballard

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and Reiser 2004). Although target costing (Ansari et al. 1997; Clifton et al. 2004; Cooper and Slagmulder 1997) originally shared some of the spirit and methods of value engineering (Dell'Isola 1973), Sutter Health in California shifted the focus for target costing from that of cost reduction to one of value creation, and began testing and systematizing target costing procedures in earnest on their San-Francisco-based Cathedral Hill project (Ballard and Rybkowski 2009; Denerolle, S. 2013, Rybkowski 2009). The Sutter Health team re-christened the process as Target Value Design (TVD), meaning that in addition to plotting a progressive reduction in a project's estimated capital cost, a TVD team also began incorporating decision-making tools to help stakeholders maximize value for the facility owner. Tools of choice for TVD practitioners include co-location, A3s, Suhr's *Choosing by Advantages* (Suhr 1999), and full scale cardboard mock-ups especially for healthcare facility projects. A statistical analysis has shown that capital projects delivered by TVD cost 15-20% less than traditionally delivered projects (Do 2004).

Use of TVD has spread since the original Sutter Health TVD initiative. However, the challenge of TVD is that its methods are still relatively unfamiliar to stakeholders, especially those accustomed to more traditional project delivery methods such as design-bid-build. Additionally, stakeholders brought onboard a project in mid-stream need to grasp quickly the culture and tools of the Target Value Design process. This need was the primary motivation behind the research of Munankami (2012) who developed and tested the simulation on participants in a first-run study. The simulation has been come to be known by a moniker: *The Marshmallow TVD Simulation.*

THE TARGET VALUE DESIGN FRAMEWORK

The Marshmallow TVD Simulation was developed to help participants intellectually grasp a simplified, conceptual framework of TVD as shown in **Figure 1.**

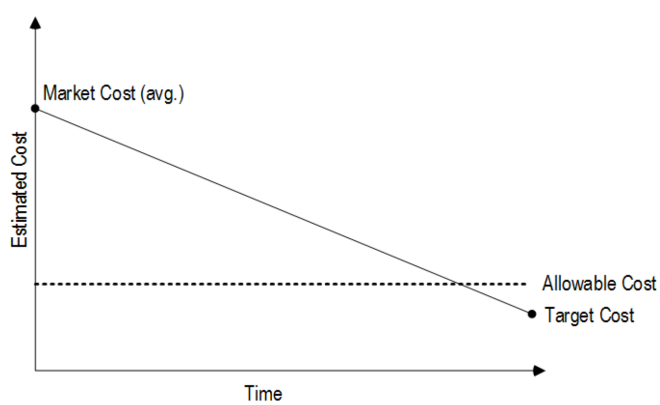

Figure 1. Key longitudinal costing milestones of TVD. *Source:* Adapted from Rybkowski (2009; p. 131, Fig. 47)

The horizontal axis represents time and the vertical axis represents estimated cost. During validation, a *market (or validated) cost* is first estimated, establishing a benchmark against which to measure future cost savings. *Allowable cost* represents that which the owner can pay and still generate a financially viable project. A co-located project delivery team must extract waste from the project using iterative design such that the estimated cost of the project does not exceed *allowable cost*. If allowable cost cannot be reached, the project is shelved. Below the allowable cost is the *Target Cost*. Unlike allowable cost which represents a critical “go-no go” project goal, target cost represents a stretch goal which is desirable to reach though not absolutely essential, thus permitting different ways to contractually create incentives for the team. A flow chart of the TVD process is represented in Ballard (2008, figure 5, pg. 8). Macomber et al. (2005; 2008) proposed seven and then nine foundational practices for Target Value Design. In 2009 and 2011, Ballard published a benchmark and update on tested TVD processes.

To motivate collaborative decision-making by stakeholders and permit funds to flow across traditional disciplinary boundaries, TVD projects often adopt two distinct compensation frameworks, one to carry design between market cost and allowable cost (“pain-sharing”), and other to carry it between allowable cost and target cost (“gain-sharing”). The pain-sharing portion of TVD exercises demands a sharing of risk: participating stakeholders place all profit in an “at risk pool,” paid to them only if allowable cost is reached. In return, the building owner commits to paying all direct costs related to development of the design even if the construction is shelved. Once allowable cost is reached, profits are released to participating stakeholders and the rules transition to a “gain-sharing” phase. During gain-sharing, additional cost savings are divided between the owner and participating stakeholders, where the percent share allocated to the participating stakeholders successively increases according to pre-established guidelines (Lichtig 2006; Matthews and Howell 2005; Rybkowski 2009).

The MacLeamy Curve (AIA 2007; MSA 2004) conceptually illustrates how cost of design changes increase over time as a project’s development progresses; however ability to impact cost and function happens early. In traditional project delivery, key stakeholders arrive too late to impact change. By contrast, in an integrated project delivery system, stakeholders are involved earlier in the process and have the ability to impact cost. The intent of integrated project delivery is that cost reduction comes not with cheapened design, but rather by extracting wasteful practices from the process. Perhaps unsurprisingly, Integrated Project Delivery has been gaining a following (Bard 2010; Burkhalter 2011; Carbasho 2008).

SIMULATION DEVELOPMENT

Instructions for Play

Stakeholders introduced to TVD for the first time may be unfamiliar with both the process and terms used. Playing live simulations introduces clarity; it facilitates an experiential “lightbulb moment” among stakeholders that is often more vivid than an instructional lecture alone (Boersema 2011, Rybkowski and Kahler 2014; Rybkowski et al. 2008; 2012; Sacks et al. 2007; Smith and Rybkowski 2013; Tommelein et al. 1999; Verma 2003). The TVD simulation developed by Munankami (2012) builds on Peter Skillman and Tom Wujec’s *Marshmallow Challenge* (Skillman 2006; Wujec 2015). Two versions of this simulation were developed: (a) a **50-minute** version that primarily illustrates the basics of collaborative cost savings using TVD, and (b) an extended **1-hour-20-minute** version that not only illustrates the basics of collaborative cost savings using TVD, it also introduces participants to the value of integrated processes over traditional processes. The durations for the simulations align with those of typical US-based university class periods.

During both versions, the facilitator projects a spreadsheet of costs onto a wall. Participants are introduced to the concepts of Estimated Cost, Market Cost, Allowable Cost, and Target Cost as shown in Figure 1.

Materials required

In both versions of the game, the following materials are required: masking tape, bamboo skewers, drinking straws, uncooked spaghetti, coffee stirrers, and marshmallows (**Figure 2**). Also needed are a two-foot-long ruler (approx. 60 cm), tables for the teams on which to construct towers, pencils, erasers, pencil sharpeners, paper, a laptop computer (or equivalent) and projector to facilitate display of a costing sheet as well as a spreadsheet.

Figure 2. Materials required for simulation (Munakami 2012)

50-MINUTE VERSION

This version of the developed TVD simulation requires teams of 3-5 participants each to build a table-top tower with a marshmallow on top in two 15-20 minute rounds. The facilitator instructs all teams: "The Owner wishes to design and build a tower that is 2 feet tall (approx. 60 cm), that is capable of holding a marshmallow at the top, and that is no more than 2 inches out-of-plumb. The tower must be constructed with supplied materials and must be free-standing (i.e. cannot be taped to a table)."

During the *Round I*, market cost is established. The teams collaboratively construct the tower without regard for cost during the design process. Cost is calculated only after the tower is complete and teams are given access to a costing sheet (**Figure 3**). Before Round II, market cost is calculated as the average cost of all towers constructed during Round I. Allowable Cost is determined to be 20% lower than the market cost. Target Cost is then the average declared by individual teams as a stretch goal and should be lower than the allowable cost (**Figure 5**). During *Round II*, teams will again develop and construct a tower, but this time will have the costing sheet available while they design the tower with the target cost as their goal. Final costs are tabulated after towers are complete. The facilitator enters numbers onto a projected (pre-formulated) spreadsheet for all to see. The facilitator leads participants in a discussion about the process.

Item	Unit cost	Number of units	Subtotal
Spaghetti sticks	$1.00		
Coffee stirrers	$5.00		
Drinking straws	$2.00		
Bamboo skewers	$3.00		
Masking tape (per joint)	$0.50		
Profit (10%)			
		Total Cost:	

Figure 3. Costing sheet

ONE-HOUR-20-MINUTE VERSION

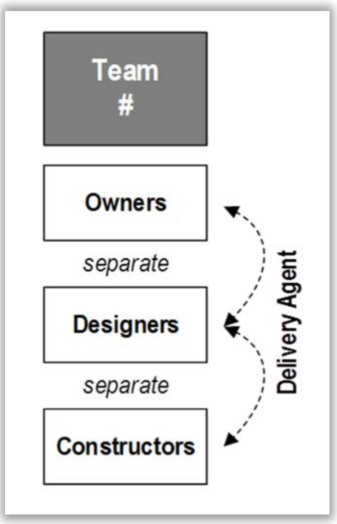

Figure 4.

This version of the simulation is similar to the 50-minute simulation, but allows stakeholders to also experience outcome differences between a linear, silo-ed delivery process and an integrated, co-located, TVD delivery process. Tallies of costs onto a project spreadsheet are made similar to the 50-minute version of the simulation. The main difference is that during *Round I* (linear delivery) teams of 4-6 players representing owners, designers, constructors, and a delivery agent, design and construct the described marshmallow-topped tower while physically isolated in separate rooms or spaces; their communication is restricted to sketching and writing (**Figure 4**). In this version, team members are also given the costing sheet at the beginning of the round and instructed to minimize cost as much as possible, though no costing goals are specified. This setup is intended to simulate a traditional process such as Design-Bid-Build (DBB). The delivery agent carries design sketches, RFIs (Requests for Information) and COs (Change Orders) between isolated team members. This round takes approximately 40 minutes to complete. Note that not only tower costs should be calculated after the round, but numbers of RFIs and COs, and time to complete the exercise should also be tallied. During *Round II* (integrated delivery) stakeholders are brought together into the same room to develop a design through co-location. This is intended to simulate a Lean-Integrated Project Delivery process. This round takes 15-20 minutes to complete. Again the number of RFIs and COs, and time to complete should be added to the spreadsheet for comparison with Round I. Numbers of RFIs and COs should be zero for Round II of course since the team is fully co-located.

Note that for the 50-minute simulation the independent variable (e.g. modification from control group) is the *presence of the costing sheet during design* (the sheet is not present during Round 1 whereas it is present during Round 2). However, during the 1-hour-20 minute simulation, the independent variable is *co-location* (team members are silo-ized during Round 1 whereas team members are co-located during Round 2). Dependent variables are metrics collected. Both versions illustrate TVD but invite different "light bulb moments" and levels of facilitated discussion.

Post-Simulation Discussion

Once all rounds have been completed, the facilitator invites discussion guided by the following questions: (a) What were some basic differences between two rounds? (b) How did the decision-making processes differ between the two rounds? (c) Which round was more stressful to you? (d) Which round offered better cooperation? (e) In which real life circumstances might Round 1 be more appropriate? How about Round 2? (f) What types of contractual arrangements and policies do you think would motivate better performance if Round 2 were an actual project? (g) How might these process be applied to your real life projects? Because the simulation is intended to enhance understanding of TVD-IPD before being implemented on an actual project, the facilitator should then transition to a different discussion following play, linking lessons learned from the simulation to actual TVD case study projects (Denerolle 2013; Do et al. 2014; Rybkowski 2009).

ROUND I: Establish Market Cost, Allowable Cost, and Target Cost

		TEAM A		TEAM B		TEAM C		TEAM D		TEAM E	
	Unit cost	No. of units	Subtotal	No. of units		No. of units		No. of units		No. of units	
Spaghetti sticks	$1.00	3	$3.00	6	$6.00	9	$9.00	0	$0.00	4	$4.00
Coffee Stirrers	$5.00	21	$105.00	1	$5.00	11	$55.00	8	$40.00	8	$40.00
Drinking straws	$2.00	30	$60.00	12	$24.00	5	$10.00	24	$48.00	16	$32.00
Bamboo skewers	$3.00	16	$48.00	15	$45.00	2	$6.00	8	$24.00	4	$12.00
Masking tape (per join	$0.50	17	$8.50	9	$4.50	3	$1.50	8	$4.00	8	$4.00
Subtotal			$224.50		$84.50		$81.50		$116.00		$92.00
Profit (10%)			$22.45		$8.45		$8.15		$11.60		$9.20
TOTAL			$246.95		$92.95		$89.65		$127.60		$101.20

Establish Target Cost

Market Cost Cost (= average of all towers)	$131.67				
Allowable Cost (=20% lower than Market co	$105.34				
Teams Declare **Target Cost** preferences	94.31	80	85	70	85
TARGET COST	82.86	(=average of all declared TCs)			

ROUND 2: Design to Target Cost

		TEAM A		TEAM B		TEAM C		TEAM D		TEAM E	
	Unit cost	No. of units	Subtotal	No. of units		No. of units		No. of units		No. of units	
Spaghetti sticks	$1.00	1	$1.00	4	$4.00	1	$1.00	0	$0.00	4	$4.00
Coffee Stirrers	$5.00	0	$0.00	0	$0.00	6	$30.00	0	$0.00	4	$20.00
Drinking straws	$2.00	3	$6.00	12	$24.00	3	$6.00	6	$12.00	2	$4.00
Bamboo skewers	$3.00	9	$27.00	9	$27.00	6	$18.00	8	$24.00	4	$12.00
Masking tape (per join	$0.50	13	$6.50	0	$0.00	1	$0.50	4	$2.00	4	$2.00
Subtotal			$40.50		$55.00		$55.50		$38.00		$42.00
Profit (10%)			$4.05		$5.50		$5.55		$3.80		$4.20
TOTAL			$44.55		$60.50		$61.05		$41.80		$46.20

Figure 5. Spreadsheet for tabulation of tower costs after Rounds I and II.

SIMULATION TESTING

To test the effectiveness of the developed TVD simulation, 24 design students and 24 professionals were recruited to test a first-run study of the 1-hour-20 minute version of the simulation. The students were from the Acme Engineering College, Department of Architecture, Purbanchal University in Kathmandu, Nepal. (**Figures 6, 7**).

Post-play Questionnaire

Following play, participants were asked to complete a questionnaire about their experience playing the simulation using a Likert scale, where 1 represented "not effective at all" and 5 represented "very effective" with respect to the effectiveness of the simulation in explaining the following: (A) mutual respect and trust; (B) mutual benefit and reward; (C) Collaborative innovation and decision-making; (D) early involvement of key partners; (E) early goal definition, (F) intensified planning; (G) open communication, (H) appropriate technology, (I) organization and leadership. They were also asked to define their understanding of Market Cost, Allowable Cost, and Target Cost, in their own words.

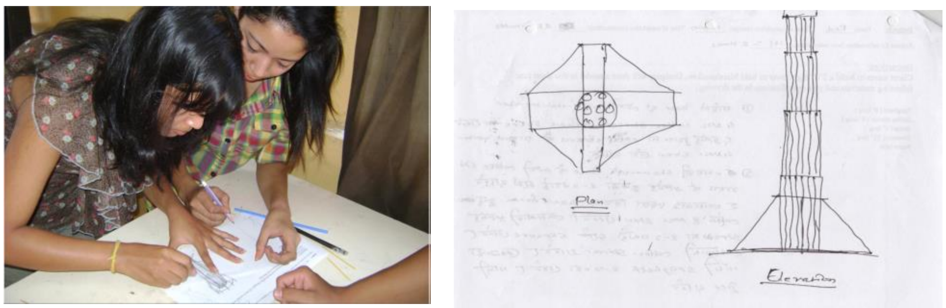

Figure 6. *Round One:* Separation of owners, designers and constructors communicated through sketches, requests for information, and change orders (Munankami 2012).

Figure 7. *Round Two*: Once target cost was established, teams co-located and worked collaboratively to re-design the tower to meet target cost (Munankami 2012).

Results from Questionnaire

Graphed results from questionnaire responses are shown in **Figure 8**. A histogram and box and whisker plot suggest the game was most successful in items G (intensified planning), C (collaborative innovation and decision-making), and D (early involvement of key partners), and least successful in item E (early goal definition). However, it must be acknowledged that this represented a first run study and that the simulation requires additional testing. There was also the possibility of respondent bias because most participants knew the facilitator well as he was a graduate of the tested university.

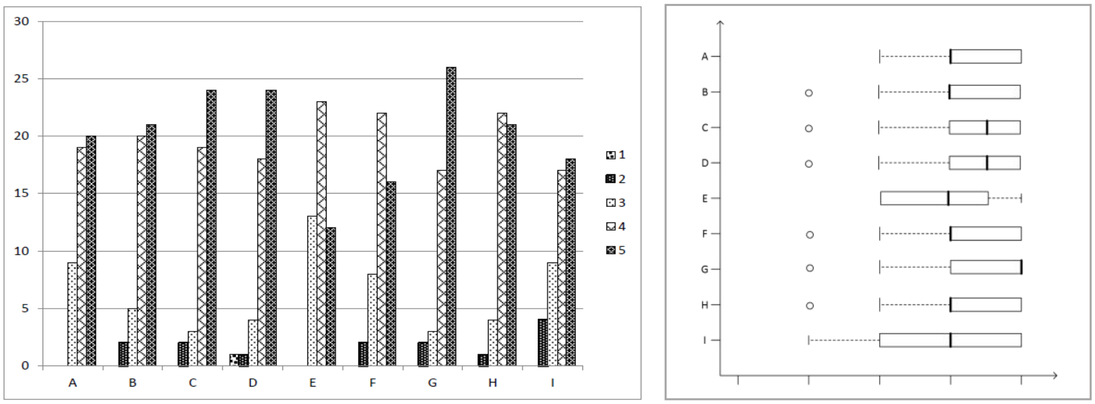

Figure 8. Tabulation of results from questionnaire following first-run study testing of TVD simulation (Munankami 2012).

DISCUSSION

The Marshmallow TVD simulation developed by Munankami (2012) has been played and tested since 2013 at Texas A&M University's Department of Construction Science courses in Lean Construction; in 2014 by Carolina Asensio Oliva, University of Campinas, Brazil; at the 2015 Associated Schools of Construction Conference, College Station, TX; and by lean consultant, Tobias Guller of *Lean Ingenieure* in Germany who requested instructions from our laboratory and has since translated the simulation instructions into the German language. In 2015, Paul Ebbs (2015) reached out to our laboratory for instructions, which we sent, and described on his blog successfully implementing the simulation at a Boise State University workshop to prepare 30 practicing professionals for application of TVD on an actual project. Those who have administered the simulation as lean consultants or in classrooms have shared feedback with the first author and have made some adaptations to suit the needs of their local constituencies. While most who have administered the simulation report it effectively illustrates and teaches TVD, some have expressed concern that the second round of the simulation demonstrated a trending of design quality toward minimalism as cost was reduced. This is a legitimate concern and suggests opportunities to modify the simulation to also include aesthetic delineators as criteria for success.

CONCLUSION

The main objective of the TVD Marshmallow Simulation has been to help participants understand basic principles of Target Value Design (TVD) within Lean-Integrated Project Delivery (Lean-IPD) process. Two versions of the game were developed: a shorter 50-minute version and a longer 1hr-20-minute version. Initial feedback from those who have administered the simulation has been thus far positive. The simulation is already being used by lean consultants and educators at various locations worldwide. Just as with the spirit of Lean, the simulation is under continuous adaptation and improvement. Ideally the simulation should be systematically tested before TVD implementation on an actual project. However, the observation that it already has developed "a life of its own" offers some indication of its effectiveness as a way to introduce Target Value Design.

ACKNOWLEDGMENTS

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COLLABORATION IN DESIGN – JUSTIFICATION, CHARACTERISTICS AND RELATED CONCEPTS

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ABSTRACT

The purpose of this article is to understand the academic landscape on collaboration in design, its characteristics and related concepts for promoting collaboration within in the project based production systems. We aim to answer to the following three questions: How to define collaboration in design and why individuals need to collaborate during design? What characterizes effective collaboration in design? Which concepts support the development of collaboration in design? For shedding light on this subject, a literature review is conducted and applicability to Architecture, Engineering and Construction industry and project delivery are discussed. In this study, it was found that collaboration is a complex phenomenon, which explains the diversity of views and many complimentary concepts in organizational and design literature. Collaboration requires the management of material and knowledge boundaries, in order to develop common goals, processes and product. Lean construction concepts, methods and tools have helped the teams to develop collaborative design and construction practices.

KEYWORDS

Design collaboration, collaboration, boundaries, bridging boundaries, crossing boundaries.

INTRODUCTION

Within the last twenty and more years, the lack of communication and collaboration have been considered as one major issue for underperforming construction industry (Latham

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1994). Since then, overcoming these barriers have been the central issue in the industry and academia, and through these developments collaboration has been instantiated in different forms within the three domains of projects' (Thomsen et al. 2009): commercial terms, organization and operating/production system.

Currently, there are two well established, but competing views of the collaboration in design, which include the constructivist approach (Bucciarelli 2003) and the communication theory (Carlile 2004). Former acknowledges design a as a social process, a dynamic intersection of social and cultural views for developing a common understanding; and the latter stemming from the information theory and mathematics, focused on the efficiency of exchanging information and meaning between two points (dispersed locations, individuals or groups of individuals) (Kvan 2000).

The purpose of this article is to understand the academic landscape on collaboration in design, its characteristics and related concepts for promoting collaboration within in the project based production systems The paper is structured as follows: in the first section of the paper, the definition for collaboration in design together with the justification are given; successively, boundaries and boundary bridging and crossing concepts are discussed to formulate the framework for analyzing existing practices; and finally, an example of the selected practice for promoting collaboration within the construction is reviewed and analyzed based on the developed framework.

DEFINITION AND JUSTIFICATION OF COLLABORATION

In the organizational and design literature, the related levels of working together are viewed as a collaborative continuum, dependent on the degrees of intensity and formality, but also on the sharing and assessing of knowledge through its exploration/creation (divergence) and knowledge integration (convergence) (Dorst 1997; Kleinsmann 2006). Based on these concepts, we have selected the definition proposed by Andreasen et al. (2015) to describe collaboration in design: "…is the process through which actors from different disciplines share their knowledge about the design process and the design itself. This creates shared understanding related to both process and artefact, helps integrate their knowledge, and helps them focus on bigger common objectives—the final product to be designed".

As also stated by Kleinsmann (2006), the three building blocks of collaboration are evident within the definition of collaboration proposed by Andreasen et al. (2015): knowledge creation/exploration and integration between disciplines; communication; and the creation of 'shared' understanding.

JUSTIFICATION - WHY COLLABORATION IN DESIGN?

The need to collaborate has historically emerged from the division of master builder into distinct functional disciplines (Pikas et al. 2015), each operating within their own object world - different paradigms, languages and activity systems (Bucciarelli 2003). In the design process, no single member has all the knowledge and skills needed for the project or information about the current state of every industry, requiring designers and engineers to share knowledge (Bucciarelli 2003).

Pikas et al. (2015) illustrated that all design disciplines are related as they have a common goal in terms of an artefact (common denominator), causing interdependencies within individuals' design and engineering tasks that must fit together. Thus, in design and engineering, designers from different disciplines must work together for following three reasons (Koskela 2016): Needs arising from the demanding requirements (the purpose/goal of the artefact, when prior solutions do not suffice); needs arising from the design process (the timely delivery of each tasks' outputs); and needs arising from the product being designed (parts must physically fit together to deliver expected functions and behaviors).

RELATED CONCEPTS OF INTERACTION

Besides the collaboration, three other common terms used for describing the sociocultural interaction include communication, cooperation and coordination. However, communication as such is not the separate interaction, but it is the foundation for all of these interactions (Sonnenwald 1996).

Communication has been defined as a formal and transactional process for sharing information. According to Carlile (2004), the communication theory oriented design collaboration concepts emphasize the creation of shared vocabulary in order to reduce uncertainty. The focus is on the direct communication link between participants as information processing units. Communication can take place either synchronously or asynchronously, the former related to the direct and face-to-face communication, and the latter related to the usage information technologies for supporting the communication within the design processes (Emmitt and Ruikar 2013).

Besides the communication, also cooperation has been often used to describe the interactions within the design process. Organizational scientists Smith et al. (1994) defined the cooperation as an activity by which individuals, groups and organizations come together, interact and form relationships for the mutual gain and benefit. According to the Mattessich and Monsey (1992), within cooperation mission and goals of the different organizations are not considered/aligned; interaction and information sharing happen when needed; authority and resources rest within individual organizations; and control is centralized.

The other term often used to describe interaction in the design is the coordination. Crowston (1997) defined coordination as "…the management of dependencies among tasks and/or resources". According to Mattessich and Monsey (1992), coordination is slightly more formal than cooperation and expands it by focusing on the alignment of goals for compatibility; interaction around common project(s) or task(s); common planning of the project communication channels; separate but coordinated authority; some risks , control and leadership are shared; resources and rewards are mutually acknowledged.

According to the Mattessich and Monsey (1992) and Andreasen et al. (2015) within the collaboration all these aspects are more closely coupled, meaning that the common goals and interests are developed; and authority, responsibility, risks, control, leadership, resources and rewards are shared.

DISCUSSION

The need to work together has been caused by the division of labor and specialization, causing boundaries between individuals or groups of individuals, and thus the need for interaction. Levels of interaction have been understood as one continuum defined by the degrees of intensity, formality, but also as a collective creation, sharing and assessing of design knowledge. These different levels of interaction have been called cooperation, coordination and collaboration, which are distinct, yet complementary concepts. Communication as such is not a separate dimension of interaction, it is required within all three for exchanging information about goals, processes and product. Within the next section, boundaries are defined and concepts for bridging and crossing boundaries are discussed.

COLLABORATIVE BOUNDARIES AND CONCEPTS OF BOUNDARY BRIDGING AND CROSSING

COLLABORATIVE BOUNDARIES

Akkerman and Bakker (2011) provide the following definition for the boundary: "…a sociocultural difference leading to discontinuity in action or interaction. Boundaries simultaneously suggest a sameness and continuity in the sense that within discontinuity two or more sites are relevant to one another in a particular way." Similarly, Star (2010) identifies boundaries as an in-between or middle ground, belonging to the both ("both–and") and at the same time to neither of the two worlds ("neither–nor").

Sonnenwald (1996) described the five types of boundaries, which the boundary spanners try to remove by using different communicative strategies and methods: organizational, discipline, task, personal, and multiple at the same time. What is important within this category of boundaries is the different levels of communicative interactions that are required for delivering designs.

Carlile (2004) proposed fundamentally different category of boundaries, using three concepts of knowledge: difference in the amount and type of knowledge accumulated; dependence between two or more entities that need to take each other into account; and novelty of the circumstances (e.g. new customer needs that generate new requirements). Based on these he proposed three categories of sharing and assessing knowledge across boundaries (Carlile 2004): "Syntactic – Differences and dependencies between actors are known. A common lexicon is developed that is sufficient to share and assess knowledge at a boundary"; "Semantic – Novelty generates some differences and dependencies that are unclear - different interpretations exist. Common meanings are developed to create shared meanings and provide an adequate means of sharing and assessing knowledge at a boundary"; "Pragmatic – Novelty generates different interests between actors that impede their ability to share and assess knowledge. Common interests are developed to transform knowledge and provide an adequate means of sharing and assessing knowledge at a boundary." These are the three different boundaries that need to be managed in order to cooperate, coordinate and collaborate.

Based on the work by Sonnenwald (1996) and Carlile (2004), boundaries can be divided into two the ontological realms, material and knowledge boundaries. The former are caused by the arrangement of individuals into organizations, disciplines, tasks and physical locations; and the latter, by the paradigmatic differences in sociocultural worlds. However, it is important to note that these two do not exist separately but are entangled into the interaction of individuals working together. An example from the design process could be an architect and engineer from two separate organizations working together on a common project.

Within the organizational and design literature, several concepts have been proposed to bridge and cross boundaries. Four concepts have been central for supporting the continuity across systems/sites: boundary roles and standardized methods for material boundary bridging; and collective learning mechanisms and boundary objects for knowledge boundary crossing.

MATERIAL BOUNDARY BRIDGING CONCEPTS

Boundary Bridging Roles

Individuals acting in the middle ground have different roles for the purpose of supporting continuity of working together (transition and interaction across different sites) (Akkerman and Bakker 2011). Sonnenwald (1996) defined boundary bridging role as "…communication and information processing behavior between two or more networks or groups" and identified several boundary crossing roles: the internal star (individuals within project/organization/department members occurred more frequently), external star (individuals who had a high frequency of communication external to their project) and gatekeeper (individuals who had a high frequency of interaction both outside and inside their projects). Each of these roles are using different strategies and methods to do the boundary bridging. What is important in Sonnenwald (1996) concept is that the design participants may assume one or more roles within the team communication and collaboration, and these in turn are dependent on the context and content of the design and process.

Standardized Methods

While studying the collaborative working of scientists and novice workers, Star and Griesemer (1989) introduced also another concept, which they named standardization of methods. They characterize methods standardization as follows: "…methods standardization allowed both biologist and collectors to find a common ground in clear, precise, manual tasks." What this says about the interaction is that it is not just redesigning of the organizational structure, but it is the quality of the implementation of methods that help to promote the team working (Majchrzak and Wang 1996). In addition, managers should consider the constraints and possibilities provided by technology, the work processes, the existing organizational culture, and the organization's strategic mission. Interestingly, the standardized methods have often been neglected from the discussions of Star's original contribution (Akkerman and Bakker 2011; Koskela 2015).

KNOWLEDGE BOUNDARY CROSSING CONCEPTS

Learning Mechanisms for Boundary Crossing

Within the design and organizational literature, many different models for learning mechanisms have been proposed. Katzenbach and Smith (2005) defined team as "…a small number of people with complementary skills who are committed to a common purpose, set of performance goals, and approach for which they hold themselves mutually accountable".

For the formation of teams, “shared understanding” is required between individuals. However, what does shared understanding mean? Moller and Tollestrup (2013) concluded that it is not the ‘shared understanding’ of the team members, but ‘sharedness’, as meaning making or framing is 100% individual. This means that it is the capacity of re-learning by individual that defines the reflective practitioner (Schön 1984). Thus, designing within teams is about learning and re-learning.

Engeström (2000) proposed a stepwise cycle of horizontal expansive learning, including questioning, analysis, modelling, examining and implementing. A crucial triggering action in the expansive learning process is the conflictual questioning of the existing collective but also individual standard practices (Engeström et al. 1997). Questioning leads to deepened analyses of the design, which in turn means sharper and more articulated questioning. Thus, actions of questioning and analysis are aimed at finding and defining problems and contradictions behind them (Engeström 2000). The third strategic action in expansive learning is modelling, involved already in the formulation of the problem and results of the analysis of contradictions. This process concludes with the actions of examining and implementing the new model in practice (Engeström 2000). In summary, collective learning is a process, requiring continued negotiation and combination of different perspectives and conceptualizations.

Boundary Objects

Star (2010) defined object as a thing, composed of “more or less well-structured stuff“ in pragmatist as well as in material sense. She defines object something that people act towards or with, while having a certain intention. This means that boundary objects provide a syntax for the intersecting work of knowledge domains, allowing the exploration of semantic differences and help the joint transformation of knowledge between practice communities (Carlile 2004). Furthermore, boundary objects are central to both the representation of past learning and the construction of new meanings (Carlile 2004).

The form of the boundary object derives from “information and work requirements” (Star 2010). Based on its form, Star and Griesemer (1989) categorized boundary objects into four categories: repositories (ordered piles of objects); ideal type (abstract and conceptual representations); coincident boundaries (common objects which have the same boundaries but different internal contents); and standardized forms (devised as methods of common communication across dispersed work groups). These objects have different capacities to represent the common knowledge (Carlile 2004).

Later, Star (2010) elaborated on boundary objects and identified three basic concepts: interpretive flexibility; the structure of information and work process needs and arrangements; and the dynamic between ill-structure and more tailored uses of the objects. The first means that the same object can be used for different purposes; second how boundary objects provide continuity of doing things together; and thirdly, using boundary object as means for moving between ill- (group) and well-structured (individual) social worlds. Thus, Bowker and Star (2000) defined boundary objects as four-dimensional and complex artefact, being temporal, based in action, and subject to reflection and local tailoring all at once. Boundary objects are dynamic in nature, having different meanings over time.

Discussion

It is the division of labor and specialization that have caused the material and knowledge boundaries between individuals or groups of individuals, who have their own paradigms, languages and activity systems. Consequently, for supporting the continuity of collaborative working at the boundaries requires: individuals filling in boundary crossing roles; standardized methods to promote the quality of teams working; learning and re-learning at the boundaries; and usage of mediating boundary objects.

For the purpose of this article, two categories of boundaries are disentangled and an initial analytical framework is proposed as shown in the Table 8. Moving on the vertical axis, between and within organizations, disciplines, tasks and individuals, requires persons filling in boundary crossing roles and standardized methods to define and communicate common vocabulary, meaning or interests; and moving on horizontal axis requires using collective learning and usage of boundary artefacts. One can use the framework to ask for example following questions: How to manage 1) Organization and syntactic boundaries, 2) Organization and semantic boundaries and so on.

Table 8. Collaborative design framework.

Boundaries		**Syntactic**	**Semantic**	**Pragmatic**
Collective	Organizations	**Goal:** Common vocabulary (syntax) to reduce uncertainty **Temporal:** Formally structure	**Goal:** Common meaning **Temporal:** Processes for developing a shared meaning	**Goal:** Common interests and goals to work towards **Temporal:** Processes for defining
	Disciplines			
	Tasks			
Individual	Personal			

Managing material boundaries: Boundary Crossing Roles and Standardized methods

Managing knowledge boundaries: Learning Mechanisms (questioning, analysis, modelling, examining and implementing) and Boundary Objects

REVIEW OF LEAN CONSTRUCTION PRACTICES

From the above it is clear that collaboration in design is described by different levels of the interaction, named cooperation, coordination and collaboration. Moving between these different states and levels of interaction requires bridging the material boundaries and crossing the knowledge boundaries. What is important to note is that collaboration is a continuous process. Within following, we shortly review some of the key lean construction (LC) practices for the bridging and crossing of boundaries, which need to be analyzed more in-depth within the future research.

Boundary Bridging Concepts in Lean Construction

In LC, several different concepts and methods have been proposed to bridge the material boundaries. Few include the co-location within the 'big room', for bringing individuals physically closer to each other in order to shorten the communication pathways (Dave et al. 2015); the last planner system as a standardized operating system for collective planning, execution and improvement of the production system (Ballard 2000); and the leads of the cross-functional teams to do boundary bridging by communicating and coordinating information and work between different clusters and within clusters (Do et al. 2015).

Boundary Crossing Concepts in Lean Construction

Some of the boundary crossing concepts in LC include: choosing by advantages, which is a process comprising of the set of methods for argumentative, collaborative and holistic decision making (Suhr 1999); value stream mapping as a visual tool for documenting and visualizing all the steps in the workflow that add value or do not add value to the final deliverable from the perspective of the customer (Rother and Shook 2003); an A3 report with a structured layout providing a methodology for the initiation, development, sharing, and documentation of ideas, problems and information within organizational setting (Sobek II and Smalley 2011); and building information modelling (BIM), which according to the stage of the project progress can have different meanings, it can act process facilitator but also as a representation of collective knowledge (simply a model) (Eastman et al. 2011). Thus several of these concepts act as boundary objects and learning mechanisms at the same time.

CONCLUSIONS

Collaboration is a complex phenomenon and many partially or fully overlapping concepts have been proposed. It is a process of creating/exploring, sharing and integration of knowledge, requiring the management of material and knowledge boundaries in order to develop common goals, processes and product. Bridging the material boundaries requires individuals filling in the boundary bridging roles and standardized methods of working together. Crossing the knowledge boundaries requires collective learning by means of debating, negotiating and combining of different perspectives and conceptualizations of vocabulary, meaning and interests. In lean construction many concepts, methods and tools have been developed to promote collaboration within the design and construction process. Some of these include co-location, ‘big room’, last planner system, and the leads of the cross-functional teams for boundary bridging; and choosing by advantages, value stream mapping, A3 report and building information modelling for boundary crossing. The scope of this research is limited as only a handful of concepts related to collaboration were discussed. For example, we have omitted to discuss the activity system theory, grounding and mediating artefacts, to name a few. Furthermore, several questions remain that need to be addressed in the future research: Which other concepts of collaboration in design exist; how to measure collaboration in terms of understanding the most influential factors of success; how collaboration influences the design process outcome; and finally, is collaboration always needed?

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ENHANCING VALUE FOR END USERS—A CASE STUDY OF END-USER INVOLVEMENT

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ABSTRACT

This paper explores the understanding of value in university buildings and tries to identify how value for end users can be obtained through end-user involvement in the pre-design stage of university buildings projects through a case study. The results from Statsbygg's (SB) customer satisfaction surveys from 2010 to 2014 have revealed decreasing customer satisfaction in the sector. Consequently, several lease agreements have not been renewed due to dissatisfaction with the building mass offered and lack of consultation with end users.

The results of the case study show that value-enhancing elements of university buildings in Norway create optimal conditions for teaching, learning, and research. To achieve adaptability in the building, which is needed to meet rapid changes in academia, end-user involvement in the pre-design phase, with a focus on excellent communication, an understanding of end-user value, and innovation, is valuable and necessary. This study indicates that further studies implementing strategies such as including the use of Building information modeling (BIM) tools and appointing a user coordinator with technical competence are recommended to give a better understanding of the advantages of optimal end-user involvement.

KEYWORDS

University buildings, value-enhancing elements, collaboration, end users, Lean Construction

INTRODUCTION

Statsbygg (SB) is the Norwegian government's facilities manager and fills the role of owner in public construction projects. With a total area of 800,000 m^2, universities form the largest part of SB's portfolio. In recent years, the results from SB's customer satisfaction surveys from 2010 to 2014 have revealed a decreasing customer satisfaction in the sector. Consequently, several lease agreements have not been renewed due to dissatisfaction with the building mass offered and a lack of consultation with end users.

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Additionally, a white paper addresses the fact that the university sector in Norway is undergoing significant transformation due to the introduction of new education practices and technological advances (Regjeringen, 2015). Modern, adaptable, and appropriate buildings with the focus on value creation for end users may enable the build environment to meet the standards required for achieving positive change (Regjeringen, 2015).

SB has previously implemented Lean Construction (LC) methods to increase productivity and eliminate waste in the construction phase. Ensuring value throughout the lifetime of buildings has not, however, received the same level of consideration. Value creation is the end goal of all construction projects (Emmitt et al., 2005), and the concept of value should cover the whole life cycle of the built facility (Rooke et al., 2010). Hence, a continuous effort to understand value creation for end users is essential.

This paper presents the results of research on value-enhancing elements of university buildings and tries to identify, on basis of a case study, how value for end users can be obtained through end-user involvement. It addresses the following two research questions:

1. What elements enhance value for end users of university buildings?
2. Which strategies for end-user involvement are required in the pre-design stage to enhance end-user value?

THEORY

In order to uncover what value-enhancing elements for end users in university buildings are, it is imperative to define the nature of value and value creation for end users.

UNDERSTANDING VALUE AND VALUE CREATION

Value is dependent on the theoretical context, as well as on subjective perceptions and evaluative judgments (Drevland and Lohne, 2015). Most often, value is expressed in mathematical terms as the relationship between cost and benefit (Kelly, 2007, Bell, 1994). Within the context of Lean Construction, however, arguably the most common definition is noted by Drevland and Lohne (2015) to be that of Womack and Jones (1996), who consider the real value of a good or service only to be defined by the final customer. Correspondingly, Liker (2012) defines value as what the customer wants, and customer satisfaction is identified as an important criterion for the success of a project (Kaplan and Norton, 1996). In this paper, end users are the primary focus for the analysis of value.

The industry's current understanding of value is such that it routinely fails to consider the relationships between buildings and users (Thomson et al., 2003). In the construction industry, the processes in the pre-design phase can appear to be hurried, resulting in customers' expectations being unrecognized (Bell, 1994). As a consequence of such phenomena, Hjelmbrekke and Klakegg (2013) emphasize that traditionally a building project is based on project organizations that leave the users in a half-excluded/part-included position.

Value creation in the operational phase occurs through the project's future users. Thus, the users' perspective of value is essential understand in order to to achieve value creation in a project (Eikeland, 1999). The public sector is the Norwegian construction industry's largest customer and accounts for 40% of the demand in the construction industry (Espelien and Reve, 2007). Consequently, what the public sector does for securing user value is of high importance to the entire construction sector – and in turn for the entire value creation of the nation.

VALUE-ENHANCING ELEMENTS OF UNIVERSITY BUILDINGS

The Norwegian government states in a white paper that functional buildings can contribute to increasing the quality of higher education and improving study and work conditions study and work conditions (Regjeringen, 2015). University facilities can be depicted as learning environments, where the focus is the users that is, the students and staff, and their interaction with the built environment (Thomas, 2012, cited by Kärnä et al., 2013). The university buildings must thus support and facilitate the universities' core activities of teaching and research to contribute value. This general picture is complicated by the fact that there arestudent groups, e.g. medical students, that need different facilities from, for instance, a group such as civil engineering students. A campus, defined as land and buildings used for university-related functions, contains several facilities with different purposes and therefore different user groups (Kärnä et al., 2013).

Several student and staff satisfaction surveys have previsously been conducted to map what contributes to student and staff satisfaction. Concerning buildings' facilities, these studies have found that the important factors that influence student satisfaction with university facilities are the quality of its social areas, auditoriums, and libraries, and aesthetic aspects of the physical infrastructure (Sandberg Hanssen and Solvoll, 2015, Wiers-Jenssen et al., 2002). Kärnä et al. (2013) maintain that factors related to the facilities and the entire campus infrastructure influence the satisfaction of staff and students alike.

The organization and activities of universities change rapidly (Bygningsstyrelsen, 2013). Hence, university facilities must be dynamic and adaptable to these changes. Furthermore, people should be encouraged to use the spaces in the university in a myriad of ways, due to the development of technology and the learning landscape (Rytkönen et al., 2012). Including business collaborations on campus and encouraging the businesses to find a natural place on campus and facilitating the creation of new solutions jointly with business is becomeing increasingly important (Bygningsstyrelsen, 2013).

We found little literature exploring facilities managers (FMs) as users of educational facilities or what value-enhancing elements for FMs are.

STRATEGIES FOR END-USER INVOLVEMENT

Planning public buildings in Norway is grounded in legislation and agreements stating that users should be involved in the process. This is motivated by the idea that users have an expertise that is significant for the planning of the building's functionality (Lefdal, 2015). SB's project mandate states that users must, through representatives, participate in the briefing. However, how this should be executed to create value for the end user is not clearly stated.

In general, the traditional view in the construction industry is that end-user interaction in the process is a nuisance (Arge, 2008). However, if client values are not fully understood in a construction project, it is likely to result in either low fulfillment of customer expectations or multiple design alterations during the project. Such changes typically lead to additional costs and frustration among the project participants (Thyssen et al., 2010).

Combined with a clear set of values, the briefing exercise and initial design operations can be managed in such a way as to reduce downstream uncertainty and associated waste (Emmitt et al., 2005).

Jensen (2011) found that the most important outcome of user involvement was that the end user felt a sense of ownership of the final result and that this led to buildings that suited the needs of the end users better. Therefore, it is essential that stakeholders are involved in the briefing and design processes (Thomson et al., 2003). End-user participation is of particular importance when a building project is part of a process of change within an organization (Jensen, 2006).

Major public projects in Norway are dependent on the quality assurance scheme of the government (Christensen, 2011) and government funding. Hence, there can be an extended period between the pre-design phase and the construction phase, which challenges the continuity of the participants engaged in end-user involvement (Hansen and Jensø, 2009). Also, both value and end users change over time (Drevland and Svalestuen, 2013, Emmitt et al., 2005), and value must cover the entire life cycle of the building (Rooke et al., 2010). Users that participate in the pre-design phase will therefore only be representative of future value creation in limited ways. Emmitt et al. (2005) highlight that a group of end users' objective view of best value will differ from individuals' perception of value. It is proposed that part of the problem with end-user involvement may be that end users find it difficult to define what creates value combined with the fact that value is difficult to measure (Spencer and Winch, 2009).

Lindahl and Ryd (2006) suggest that construction project teams should improve their skills in communicating and interacting with the end users. The users on their hand need to be skilled in choosing the appropriate experts or consultants for the task of translating end-user values into design criteria (Lindahl and Ryd, 2006). Hansen and Jensø (2006) found that one of the most important strategies used to improve both the planning processes and the final design has been establishing the building as a virtual model, allowing the users and the construction project team to both develop solutions and improve communication.

Emmitt et al. (2005) present a model of a simple design management tool that employs a value-based approach and incorporates Lean Construction thinking. A central element in this model is creative workshops that encourage open communication and knowledge sharing while trying to respect and manage the chaotic nature of the design process. Cooperation, communication, experience, and learning as a group contribute to the clarification and confirmation of project values. Additionally, Thyssen et al. (2010) acknowledge ways in which LC methodology facilitates client value creation in the pre-design phase, including translating client values into understandable design criteria and taking enough time to explore end users' needs and make the changes up front. Such exploration provides room for creativity and stimulates innovations.

RESEARCH METHODOLOGY

This paper presents the results of research based on a literature review, a widely distributed questionnaire, and an examination of one case, thus applying triangulation methodology used in qualitative research according to the presctiptions of Yin (2013).

The questionnaire was distributed to seven universities in Norway. It aimed at gaining views on value-enhancing elements of university buildings from three different end-user groups: students, employees, and FMs. All eight universities were selected on the basis of recently completed construction projects. We developed the questionnaire in collaboration with Statsbygg and Multiconsult. A total of 910 respondents completed the questionnaire (337 students, 541 staff, and 32 FMs). The data from the questionnaire was examined to find the relationships between end-user value and various educational facilities. The questionnaire distributed consisted of questions that asked the respondent to rank the importance of elements and facilities in the buildings.

Additionally, a case study involving one project was investigated thoroughly to find optimal strategies for end-user involvement. The university in the case study was selected because of its high response level to the questionnaire that was distributed. Construction of the new campus at this university was finished in the spring of 2014, and the pre-design phase had started nine years earlier. We were able to analyze how end-user involvement was conducted in this particular project. The study consists of ten in-depth, open-ended, semi-structured interviews with key actors, notably project managers, architects end users and FM representatives.

FINDINGS

VALUE-ENHANCING ELEMENTS FOR END USERS

The interviewees were asked to state what, in their opinion, value consisted of in the context of university buildings. Their responses indicated that value for end users is a building that creates optimal conditions for teaching, learning, and research. Additionally, the interviewees were asked whom they considered the end users of a university building to be; the responses stated that end users were thought to include students, staff, FMs, and the community. FMs, however, felt that they had not been involved to the same degree as other users in the earliest stages of the project.

The ranking of eight room functions was modeled and is presented in Table 1 and Table 2. The results were examined separately to reveal potential variances between the views of students and staff. Group/meetingrooms and studyhall/private offices are ranked as number one by students and staff respectively, and so on. The results show that the standard deviation is high, indicating individual preferences and different interpretations of what value is. In addition to the functions set out in Tables 1 and 2, several elements are highlighted as important factors for students and staff. These are as follows: a campus should be located near a city, there should be access to public transportation and bicycle parking, the opportunity for physical activity on campus, and the opportunity for interaction with businesses on campus.

Table 1: Room functions ranked from most to least important—students

Element	Mean	SD
Group/meeting rooms	2.10	1.29
Study hall/private offices	2.51	1.85
Auditorium	3.39	2.27
Library	3.44	2.05
Informal break facilities	4.10	2.23
Cafeteria	4.48	2.08
Laboratory	4.75	3.10
Workshop	5.39	3.07

Table 2: Room functions ranked from most to least important—staff

Element	Mean	SD
Study hall/ private offices	1.44	1.25
Group/meeting rooms	2.27	1.46
Auditorium	2.74	2.28
Library	3.10	2.40
Informal break facilities	3.34	2.39
Laboratory	3.40	3.31
Workshop	3.75	3.51
Cafeteria	3.78	2.73

We also examined the essential elements for FMs. The results show that access to technical rooms, easy control of technical installations, a central operation control system that controls all functions, and an effective fire and emergency evacuation plan are the most important factors for FMs.

On an organizational level, we asked the administrative staff how the building design contributes to or prevents the university achieving its primary goals on a corporate level. The design of the current university buildings in Norway does not necessarily support the achievement of each university's strategic organizational goals. We also found that the building design lacked adaptability in relation to the changes in teaching methods and new technology and resulted in an inefficient utilization of space.

STRATEGIES FOR END-USER INVOLVEMENT

The case study of one project was investigated thoroughly to find optimal strategies for end-user involvement. The university studied began processes for co-locating and fusion in 1994, moving from having institutions at six different locations to only one. The new university building is 54,660 m^2 and accommodates approximately 5000 students and 500 employees.

It was confirmed by all interviewees that user involvement was executed in line with SB's mandate. The mandate states that end users should participate in preparation of briefs. The end user should, as part of this process, describe their future organization and the specific needs that it will have.

The university appointed user-group representatives from the university board and all academic departments. A user coordinator (UC) is the project manager's (PM) contact. It is the university's responsibility to select a UC. All communication from the user to the PM goes through the UC. A UC employed in the university's construction engineering department was chosen. Several respondents noted that it was crucial for the implementation of user involvement that the UC had previous experience of construction processes and design possibilities.

It is expressed by the users that Statsbygg should have informed them that any changes in decisions they make in the course of the project after completion of the brief might have unfortunate consequences for progress and costs. The project paused from 2006 to 2009. In 2009, funding was granted. The university found that by then teaching and learning methods had evolved. So, when the engineering and design phase commenced, the brief from 2003 were found to be representative of the end users' current needs. Representatives from the university explicitly stated that they felt that it had not been communicated clearly by Statsbygg that the brief could not be changed. All parties involved expressed the view that the users were in agreement about what elements would create value. However, the length of the project acted as an obstacle in communicating value for end users since the end users had changed and technology had advanced. The users felt they were not challenged enough to be innovative with design solutions, stating that the university was built for the needs as they were in 2003, not for its future needs.

The PM and the UC determined the extent of user involvement and agreed on expectations throughout the pre-design phase, arranging workshops and meetings with the user organization and SB. However, the interviews did not reveal any specific strategies that would be implemented to preserve user value. Respondents from the project organization and the university stated that they found the communication and collaboration to be reasonable. The discontinuity of PMs and members of the user group due to the long time frame of the project led to complications in communication and the traceability of previous decisions. The university found it difficult to understand the magnitude and complexity of the project and what was required of the organization to make the right decisions.

It was highlighted by the key actors that creating a common understanding of the terminology and design solutions is imperative to understand the end users' needs and improve communication. The former facilities manager of the university expressed a need for a BIM tool that would be easy to use to demonstrate effortlessly the design alternatives discussed with the end users. One of the PMs said that trips taken to other universities in Norway helped the user groups and the SB project organization create a common ground for further discussions.

DISCUSSION

VALUE-ENHANCING ELEMENTS FOR END USERS

The literature and interviewees concur in that value is a building that creates optimal conditions for teaching, learning, and research. The results of the questionnaire show that the standard deviation is high, suggesting that there is a high level of variance in the perception of what the most value-enhancing elements are. The case study reveals that the users agreed on what elements would create value. However, the length of the project acted as an obstacle in communicating value for end users since the end users changed and technology advanced. Hence, users that participate in the pre-design phase will only be representative of future value creation in limited ways. The importance of innovation is critical. The literature supports the view that value is dependent on subjective perceptions and that both value and customers change over time. Even so, the findings from the questionnaire correspond with studies from the literature showing that special rooms such as workshops, laboratories, auditoriums, and libraries, as well as social elements such as a cafeteria and informal break facilities, are very important.

The inappropriate design of current universities' buildings in Norway counteracts adaptability. The importance of adaptability in buildings is emphasized in the literature, as the spaces in a university should be used in different ways to adapt to the development of technology and the learning landscape. It was discovered in the case study that more time spent on innovative design in the pre-design phase might contribute by creating an ability to adapt to the changes that could take place at the university in the future.

The literature shows that FMs were only to a limited degree included in the pre-design process. We found no studies exploring FMs' value perspective. The case study reveals that FMs were not automatically considered as a distinguished user group, resulting in the disregarding of solutions for facility management. However, more research is necessary to draw full conclusions in this respect.

STRATEGIES FOR END USERS' INVOLVEMENT

Both the theoretical framework and the case study indicate that communicating using the same terminology, translating client values into understandable design criteria, and creating a common understanding are important for successful end-user involvement. Establishing the building as a virtual model as a basis for discussion and taking enough time to explore end users' needs and make the changes up front can contribute to fewer changes being made after design and construction starts, avoiding negative consequences for progress and the cost. Engaging the users in creative workshops with a clear agenda of preserving user value, as presented as a design management tool in the literature, can contribute to clarifying and confirming values further. The case study indicates that a UC with previous experience of the construction industry was crucial to achieving communication and interaction between the actors and end users, raising the question of whether there is a need for a technical coordinator or an academic process leader to succeed with end-user involvement, as the literature suggests.

It is important to note that it is hard to generalize the findings, due to the fact that the study is based on end-user involvement in one project only and the distributed questionnaire received an uneven number of responses spread among the chosen universities.

CONCLUSION AND FUTURE RESEARCH

The results show that value-enhancing elements of university buildings in Norway enable the creation of optimal conditions for teaching, learning, and research, including special rooms like workshops and laboratories. End-user involvement in the pre-design phase, with the focus on good communication, understanding end-user value, and innovation seem to be necessary to achieve the adaptability in the building that is needed to meet rapid changes in academia and different views of value among the end users.

The research identified the importance of having strategies, including the use of BIM tools, design management tools for user involvement, and appointing a user coordinator with technical competence, to aid communication between parties in the process, hence possibly enhancing value throughout the lifetime of the building. Even though the most significant obstacle found was the length of the public project, the case study illustrates that increased focus on end-user needs could improve the project's success. However, it appears that the competence of the user coordinator was of major importance.

Further research and implementation of the strategies used to achieve end-user involvement may give a broader understanding of the advantages of optimal end-user involvement. It is also important that the lack of facilities manager involvement is studied further in order to enhance value for both the end user and the owner.

ACKNOWLEDGMENTS

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PRODUCT VERSUS PERFORMANCE SPECIFICATION FOR WHEELCHAIR RAMP CONSTRUCTION

Nigel Blampied[1] and Iris D. Tommelein[2]

ABSTRACT

Wheelchair ramps at street intersections are a simple product of construction. In California, the standards for these ramps are established by the State Architect and are common to all agencies that own public streets and build pedestrian facilities in the state. There are 541 such street-owning agencies.

When 541 agencies produce a simple product to the same requirements, one might expect to find little difference in the cost of the product or the time taken to produce it. This proved not to be the case. A significant pattern of difference was found between the cost and time to produce ramps by the State Department of Transportation (DOT) as opposed to the cost and time to produce ramps by local cities. The differences appear to be rooted in historic practices which, in turn, are rooted in the procurement laws that govern to two types of agency. Those laws date back to 1875 and 1883 respectively, and they have led to the DOT adopting a more product-based form of specification while cities use specifications that emphasize performance. This difference in specifications drives the cost and schedule differences.

The paper illustrates the use of benchmarking between agencies and the “path dependent” influence of historic practices.

KEYWORDS

Theory, flow, set based design (SBD), product design, performance based design, transportation, wheelchair ramps.

INTRODUCTION

This paper considers a simple product of construction: wheelchair ramps at pedestrian crossings (Figure 1). These are the depressions in sidewalks that allow wheelchair riders to move from raised sidewalks into and across streets. Their engineering is simple. Structurally, they are made from an unreinforced concrete slab with a minimum thickness that is specified in US Customary Units at 3.5 inches (about 90 mm). This thickness is not determined through structural design calculations, but rather responds to experience of

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ground movement and growth of tree roots. Ramps and their adjacent sidewalks must accommodate movement of the underlying ground with a minimum of cracking. They normally carry minimal dynamic loads, e.g., a person on foot, or a person in a wheelchair.

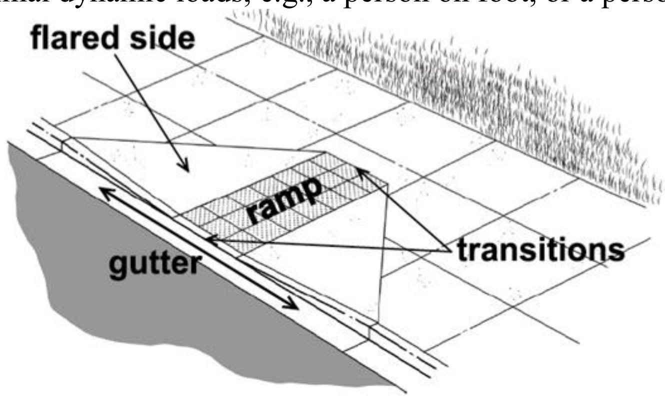

Figure 1: Wheelchair Ramp (US Dept. of Justice, Civil Rights Div. 2007)

In California, the State Architect establishes standards for such ramps. The state's streets are owned and maintained by the State Department of Transportation (DOT), 58 counties, and 482 cities. Under the Americans with Disabilities Act (ADA) each of these 541 agencies is required to facilitate the movement of wheelchair riders and blind people. Accordingly, three elements, (1) wheelchair ramps, (2) sidewalks, and (3) signals, constitute the principal elements of ADA infrastructure on streets.

Table 1 lists the standards for wheelchair ramps. A ramp is considered to be non-compliant if any of these standards is not met. Exceptions are permitted only if compliance is technically infeasible or structurally impractical (Caltrans 2013). The specifications are written in US Customary Units.

Table 1: Wheelchair Ramp Standards (specified by the DOT in US Customary Units) (Swanson 2012, modified by Value Management Strategies 2014)

Width of Ramp:48" (~1.22 m) min.	*Top Landing Length: 48" (~1.22 m) min.*
Slope of Ramp: 8.3% max.	*Top Landing Slope on Perpendicular Ramps: 2% max.*
X-slope of Ramp: 2% max.	
Flare Slope: 10% max.	*Top Landing X-Slope: 2% max.*
Gutter Slope: 5% max.	*Gutter X-slope: 2% max.*
Gutter Lip: Flush	*Truncated Domes: 36" (~0.91 m) deep x ramp width*

The DOT has issued standard plans that conform to the State Architect's requirements, and these plans are used by it as well as by counties and cities.

Construction of ADA infrastructure is sometimes included in larger projects, but many agencies issue specific contracts exclusively for ADA compliance. These specific contracts may be issued in response to lawsuits or threats of lawsuits for failure to comply with the ADA. We shall refer to them as "ADA projects."

With many different agencies issuing contracts to provide a simple and standard product, an opportunity exists to compare and learn from their delivery processes. One might expect such processes to be uniform and consistent, but our research has shown this is demonstrably not the case.

In the course of this research, we examined the bid documents and project costs data for 39 ADA projects completed by the DOT, and 9 ADA projects completed by four cities. In addition, cost data was obtained for 13 ADA projects completed by four counties, but their bid documents were not examined.

DIFFERENCES IN LAW AND DIFFERENCES IN PRACTICE

ADA projects in California are developed through a Design-Bid-Build process. The DOT, counties, and cities are all subject to the California Public Contract Code and must comply with the requirements of that code. However, different code sections apply to each:

For the DOT, Public Contract Code 10120 applies. "Before entering into any contract for a project, the department shall prepare full, complete, and accurate plans and specifications and estimates of cost, giving such directions as will enable any competent mechanic or other builder to carry them out." This law was introduced in 1875 and revised most recently in 1981.

For counties, Public Contract Code 20124 applies. "The board of supervisors shall adopt plans, specifications, strain sheets, and working details for the work." This law was introduced in 1883 and revised most recently in 1982.

For cities, Public Contract Code 20162 applies. "When the expenditure required for a public project exceeds five thousand dollars ($5,000), it shall be contracted for and let to the lowest responsible bidder after notice." This is another law introduced in 1883 and revised most recently in 1982.

The code that applies to the DOT is the most specific one of the three and it has been interpreted strictly. The code that applies to the cities is the least specific one and it has been interpreted flexibly. This becomes apparent when one examines the bid documents and payment methods of the various agencies. The DOT provides bidders with detailed plans and pays for ramps by unit volume of concrete. This requires a considerable amount of preparatory work. To prepare plans, a survey crew must create a map of each location and then employ a designer to design a suitable ramp. The designer must spend time calculating the surface area of each ramp. To obtain a cubic measure, this surface area is multiplied by the expected concrete thickness. After the ramp is built, the DOT's inspector must measure the ramp and determine its volume for payment.

By contrast, cities provide no drawings to bidders. Three of the four cities studied provide bidders with lists of locations where the ramps are to be constructed. The fourth city merely states the number of locations. That city's staff selects locations after the contract has been awarded and then provides the successful contractor with a list.

Table 2 lists the data provided to bidders by the DOT and cities and Figure 2 illustrates a DOT wheelchair ramp design provided to bidders.

Table 2: Data Provided to Bidders and Units of Payment used on ADA Projects

Agency	Provides a location plan	Provides a plan for each ramp	Lists locations with no plans	Unit of payment for ramps
DOT	Yes	Yes	No	Unit volume
City A	No	No	Yes	Each
City B	No	No	No	Each
City C	No	No	Yes	Each
City D	No	No	Yes	Each

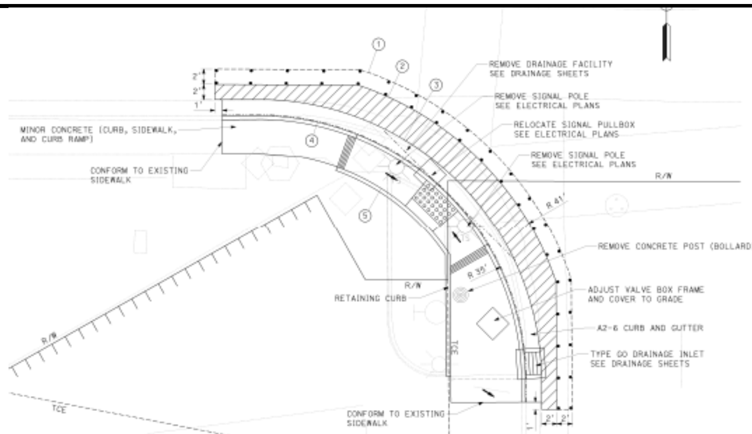

Figure 2: Example Wheelchair Ramp Design Provided by DOT to Bidders (Caltrans 2010)

EXPECTED COST FROM DOT DATA

This research began as an examination of the ADA project process in a single agency, the DOT. The goal was to determine how Lean principles and methods might improve that project delivery process. The comparison with county and city processes was added to stimulate ideas for improvement of the DOT's delivery process. The research then took a new direction when the researchers discovered how the city process differs from the DOT process. Although tangential at first, the comparison between the DOT and city processes became the principal focus of the research.

At an early stage, a best-fit exponential curve was developed in order to identify outliers in the DOT data, using data from 39 DOT ADA projects that resulted in building a total of 976 ramps, about 1,500 m (4,797 feet) of sidewalk, and four audible traffic signals. A modified Cobb-Douglas formula was used (Douglas 1974). Through successive approximations in MATLAB, the following best-fit formula was developed:

$$\text{Expected Cost} = 232{,}940 + 62{,}711 X_1^{0.2928} \cdot X_2^{0.1429} \cdot X_3^{0.3760} \cdot X_4^{0.0172} \cdot X_5^{0.1791} \quad \text{(equation 1)}$$

Where X_1 through X_5 are the following numbers plus one (to avoid that any term in the equation would take on the value 0): X_1 the number of ramps, X_2 the linear feet of sidewalk (normally 1.24 m or 4 feet wide), X_3 the number of audible traffic signals, X_4 the dollar amount paid to property owners and utility companies for right-of-way (land, easements, and utility relocations), and X_5 the number of hours that DOT employees spent in obtaining right-of-way.

This formula had a correlation coefficient R = 0.74. The modified Cobb-Douglas converged quickly and provided an intuitively satisfying result. It indicates a fixed processing cost of $232,940 per project, regardless of project size, and all the factors are positive.

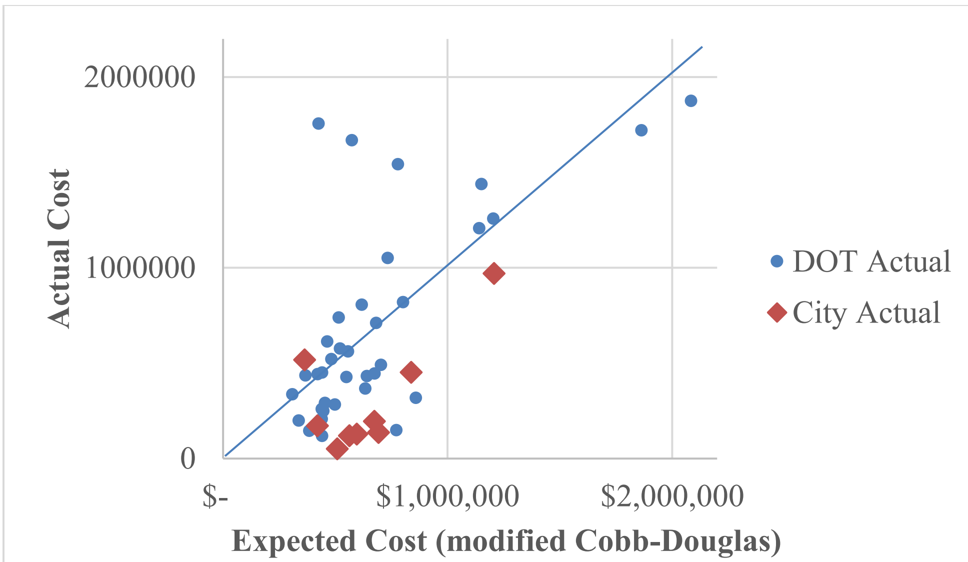

Figure 3: Expected versus Actual Project Costs

COST COMPARISON OF DOT VS CITY PROJECTS

Figure 3 illustrates the outcome of the Cobb-Douglas analysis. It compares the expected cost calculated with equation 1, on the horizontal axis, against the actual project cost on the vertical axis. A projects whose actual cost is equal to the calculated cost (expected cost) is shown by a point on the diagonal line. One that cost more than its expected cost is shown by a point above the diagonal. One that cost less than its expected cost is shown by a point below the diagonal. All but one of the city projects cost significantly less than their expected cost computer using DOT data. On average, each city project costs $347,000 less than comparable DOT projects, that is, to produce the same scope as measured by the three ADA elements.

Engineering costs on highway projects in the US are divided into Preliminary Engineering costs and Construction Engineering costs. Preliminary Engineering refers to engineering work that occurs prior to the award of a construction contract. The average cost of Preliminary Engineering for the DOT ADA projects in our sample is $346,000 per project. The closeness of this number to the $347,000 cost difference between DOT projects and city projects is coincidental, but the order of magnitude is not. Cities save this money by avoiding virtually all pre-construction design effort on their ADA projects.

The total expected cost of the nine city projects, using the modified Cobb-Douglas formula, was $5,865,185. The actual total cost of these nine projects was $2,743,594, that is, 47% of the expected cost.

An expected outcome of investing time and money in the preparation of a detailed design in a Design-Bid-Build process is that the design will provide better information to bidders and thus result in savings from more competition in bidding as well as the avoidance of problems that might arise during the construction phase. The data for ADA projects indicates that these savings did not occur. Despite their minimal designs, the cities received construction bids that were similar in price to the construction bids received by the DOT.

SCHEDULE COMPARISON OF DOT VS CITY PROJECTS

Each city in the study prepares and awards an annual contract for ADA facilities. As indicated, their designs are minimalist. With very little of the project lifespan being dedicated to design, a city project therefore takes a year or less from start to finish.

DOT projects are funded from the State Highway Operation and Protection Program (SHOPP). This program has major project and minor project components. Minor projects are defined as those having a construction cost of less than $1,000,000 (CTC 2005). The California Transportation Commission allocates funds for minor projects each year, normally in June, and these projects must be ready for construction within a year. These minor projects therefore typically have a lifespan of up to two years: one year for preliminary engineering and a second year for construction.

Projects over $1,000,000 are in the "major project" portion of the SHOPP. This is a program of projects that are to be awarded with the next four years. Construction contracts that are awarded each year are for projects that are listed in the first of the four years. New projects are then added in the fourth year, creating a continuously rolling four-year plan. The lifespan of a major SHOPP project is therefore normally longer than five years as projects are listed in the program for four years before they are awarded, and then construction takes a year or more. These processes combined with anecdotal evidence indicate that DOT projects take considerably longer to complete than city projects. This would also mean that the DOT is less able than cities to respond quickly to citizen complaints about accessibility. Cities can respond within a year, and one city can respond almost immediately.

COMPARISON IN QUALITY OF DOT VS CITY PROJECTS

Swanson (2012) examined 91 recently-completed DOT wheelchair ramps and found that 39 of them did not comply with one or more of the standards listed in Table 1. This is a 43% failure rate.

The DOT commissioned a review of Swanson's work. This found that Swanson had used outdated standards and had reported on ramps that were not part of the recently-completed projects. When adjusting for these errors, the failure rate was reduced to 13% (Value Management Strategies 2014).

The cause of this poor compliance appears to be in the process used by the DOT. Designers produce detailed designs using location and topographic data provided by their surveyors. This data requires interpolation by the designer, which introduces a measure of imprecision that may not provide the precision needed to meet the exacting requirements of the wheelchair standards, where a few millimetres can make the difference between success and failure. The construction contractors are given detailed designs and are required to build to those designs. Their responsibility is to follow the design, not to satisfy the requirements of the standards. If they build to plan but the product does not meet the precise requirements listed in Table 1, either the designer has failed or the contractor has an excuse to blame the designer.

In contrast, the city process places responsibility for compliance squarely upon the construction contractor. The contractor receives the State's Standard Plans and is required to devise a solution that meets the standards. If the product does not meet any of the requirements in Table 1, the responsibility rests solely on the contractor.

The DOT has addressed the 2012 non-compliance by issuing new design and construction bulletins (Caltrans 2013 and 2014) and by introducing Standard Special Provision requiring the contractor to survey its work and report the results to the DOT.

In meetings with DOT personnel to discuss the research findings, it was suggested that there are scope differences between city and DOT ADA projects. References were made to conflicts with traffic signals, utilities, drainage and right-of-way widths. We asked in two e-mail messages for specific locations at which we might observe these problems, but received no location information. Our hope had been that we might observe these locations and determine whether similar locations exist in city projects. City facilities also do include traffic signals, utilities, drainage, and areas of limited right-of-way.

LEAN ISSUES AND LITERATURE REVIEW

LEAN

A wide body of literature attests to the importance of empowering the front-line worker. This is particularly true of Lean literature, beginning with Ohno (1988:1 and 1988:2). The essence of Toyota's implementation of kaizen is to empower front-line workers to stop the line and get help from their supervisors to resolve problems. It might reasonably be argued that the empowerment of front-line workers (and other workers in the organization) is a core distinctive of Lean. The city process is consistent in this regard by empowering contractors to "do what is needed to deliver a project to standard."

The city process is also consistent with set-based design, in which designers keep several alternatives in play and design decisions are deferred to the last responsible moment (e.g., Parrish 2009). In the wheelchair case, cities transfer location-specific design decisions to the contractor, leaving open a set of design options for the contractor to choose from.

The usefulness of deferring decisions to the "last responsible moment" was argued by Lane and Woodman (2000), who coined the term. By effectively leaving the final design to the contractor, the cities are deferring this decision. In contrast, the DOT makes early design decisions that may be sub-optimal. When decisions are deferred, the later decisions generally produce better results because the decision makers have more complete, contextual information.

BEST VALUE

The cities' approach is also affirmed in the "Best Value" approach advocated by Kashiwagi et al. (2010). This approach advocates that decisions be made by the contractors wherever possible. Kashiwagi et al. say, "decision making by buyer's project managers [is] a risky, inefficient, and transaction causing exercise." We consider that this position is overstated: The contractor is not always the entity in the best position to make decisions but there is, nevertheless, truth to projects possibly being better off overall when designers avoid making decisions based on assumed or partial data, and defer decision making to contractor in the field, who have ready access to all pertinent data. In our example, the argument is two-fold: (1) the design of wheelchair ramps is not so complex that it must be detailed in the office by a designer and (2) a number of site-specific contextual considerations that are hard to identify a priori, may affect wheelchair ramp construction.

DESIGN INCOMPLETE AT BID

A fallacy in the Design-Bid-Build process is referring to the plans that accompany the bid documents as the "Final Design." Pietroforte (1997), building on earlier work by Hayes et al. (1988) points out that design is not complete until construction is complete. No matter how detailed the design may be at bid time, it continues to be refined or altered in construction. To go out for bid, the designer should produce a product that indicates the desired performance, that is biddable and buildable, and that will promote fair competition. In the case of the city's wheelchair ramp bid documents, this is achieved. The desired performance is that the ramp must meet the standards set by the State Architect. Many configurations at any given street corner could satisfy these standards. The mere provision of the State's Standard Plans and a location is sufficient.

The law requires that the DOT provide a bid package that can be executed by a "competent mechanic." On large projects, such as the multi-billion dollar San Francisco-Oakland Bay Bridge, this concept of a competent mechanic has been understood to include the ability to design and execute some extremely complex engineering feats. It would make no sense to suggest, then, that a competent mechanic cannot design a wheelchair ramp. The design of a wheelchair ramp does not entail any complex engineering calculations and such ramps are routinely designed and built by contractors who may not have a professional engineering registration.

CONCLUSIONS

Differences between the laws written for the California State Government and California cities in the late 1800s have led to considerable differences in DOT vs. city approaches to the delivery of equivalent products, in this study: ADA wheelchair ramps. The differences reflect the phenomenon of "path dependency," in which early decisions become enshrined in practice and limit the options available to later decision makers so that, after the passage of time, it becomes extremely difficult, and often very costly, to revisit and reverse the early decisions. Such path-dependency has been described by Morrey et al. (2012), who discuss the path of practices in a construction company that has been in business since 1890. The path dependencies in our case are of a similar vintage. Morrey et al. state that, "only when they [the path dependencies] are identified and understood can they be overcome, enabling new paths to be created." Although the paths between the DOT and cities have diverged for so long, the cities' model could—in our opinion—easily be adopted by the DOT. Adoption could encounter institutional resistance, but that should not be insurmountable.

This research began with a goal of finding lessons from projects in a single agency that could be applied to other projects in the same agency. It transpired, however, that the more useful and significant comparison was to similar projects in other agencies rather than within the single agency. The paper illustrates the use of benchmarking as a version of the Lean practice of genchi genbutsu ("go and see for yourself"). This practice normally refers to visiting, observing, and learning from events on the shop floor. Here, however, we found it useful to observe two different groups of projects producing essentially the same products and to learn how each can provide useful lessons to the other.

The DOT has indicated that if city contracts are not subject to the same third party review that is applied to DOT projects, it is incorrect to presume that city curb ramps are being constructed in compliance with the ADA.

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IMPROVING DESIGN MANAGEMENT WITH MUTUAL ASSESSMENT

Vegard Knotten [1], Fredrik Svalestuen[2], Ola Lædre [3] Geir Hansen [4]

ABSTRACT

The Architecture, Engineering and Construction (AEC) industry recognizes the understanding of the design process as a key to successful projects. With the background of Lean Construction efforts such as the Last Planner, Collaborative Planning in Design etc. the planning of the design process has improved significantly. A key part of Lean Construction is to involve the team in the planning and use metrics to check the results. Metrics and measurements in the AEC industry have traditionally focused on the performance of the project and not so much on the interpersonal relations of in the design team itself.

In this paper, we elaborate on how the Mutual Assessment (MA) can help to improve the design process, by aligning the MA with experience and current relevant literature.

Mutual Assessment (MA) is an approach for continuous improvement of the design team in a pre-planned setting. MA was developed by a Scandinavian contractor in order to improve client satisfaction. Through the use of a survey the design team evaluate each other, creating a common understanding of needed improvements. MA gives all major participants a chance to systematically assess the team, and creates room for dialogue and improvement. Improving the design teams helps align design and construction, and thereby to achieve success.

The methodical approach of the research is a single case study, based on studied documents and semi-structured interviews with a large Scandinavian contractor. In addition, a literature review of metrics, design management and teams was carried out. The research is a qualitative study focusing on MA as an important tool for continuous improvement of the design team.

The experiences from the case show that MA is an easy and accessible method to systematically improve the design team thus improving the design management process.

KEYWORDS

Lean construction, continuous improvement, collaboration, mutual assessment

INTRODUCTION

The Architectural Engineering and Construction (AEC) has a potential to increase its productivity and to increase the value of its projects (Bråthen, 2015; El. Reifi &

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Emmitt, 2013; Mejlænder-Larsen, 2015). The industry recognizes the understanding of the design process as a key to successful projects (Aquino & Melhado, 2002). With the background of Lean Construction efforts such as the Last Planner, Collaborative Planning in Design etc. the planning of the design process has improved significantly (Fundli & Drevland, 2014; Hamzeh et al., 2009). A key part of Lean Construction is to involve the team in the planning and use metrics to check the results. Metrics and measurements in the AEC industry have traditionally focused on the performance of the project and not so much on the interpersonal relations of the design team itself.

The design team or the people doing the design are important for the result. Dainty et al. (2007) points out the industry´s ability to improve are limited by how the people are managed. ”Buildings require the combined efforts of many individuals, working and designing collaboratively to provide value to their clients” (Emmitt & Ruikar, 2013). Boyle (2003) states that a key factor for achieving success in AEC projects is directly linked with the personnel involved, i.e. the team.

Mutual Assessment (MA) is an approach for continuous improvement of the design team in a pre-planned setting. MA is an experience-based approach developed by a Scandinavian Contractor in order to increase the client satisfaction in projects. Through the use of a survey the design team evaluate each other, creating a common understanding of what issues that needs to be improved. MA gives all major participants a chance to assess the team in a systematic manor, creating a room for dialogue and improvement. Improving the design teams helps to close the gap of misalignment between design and construction, and helps to achieve success.

The Lean Project Delivery System (LPDS) have implemented a learning loop that runs thru all the phases of a building project, from start to finish and back to start again on a new project. This implicates that there is a need for a planned learning thru the whole lifecycle of a building project. The authors did not find a consistent description of how this is executed, but we believe that MA could contribute to this.

In this paper, we elaborate on how Mutual Assessment (MA) can help to improve the design process, by aligning MA with experience and current relevant literature.

The paper is organized by first presenting a relevant theoretical framework, then in the findings chapter presenting how MA is carried out, and at last a discussion and conclusion chapter linking MA to the theoretical framework.

METHODS

The method of this research has the approach of a qualitative case study. A case study does not need to control behavioural events and the focus is on contemporary events(Yin, 2014). The research consisted of a review of relevant literature linked to the main parts of MA, based on the recommendations of Creswell (2003). The literature is presented in the theoretical framework chapter and its link to MA is presented in the discussion and conclusion chapter. The literature on MA seemed to be quite limited, so the authors selected to expand the scope to also include for example Balanced Scorecard and Lean Project Delivery System. The case studied is from a Scandinavian contractor chosen of their experience with MA. The study consisted of two open–ended interviews and a document study concentrating on internal descriptions of MA.

THEORETICAL FRAMEWORK

Success can be defined in many contexts but Oxford dictionary of English simply states, “Success is the accomplishment of an aim or purpose” and failure as “lack of success”. Samset (2010) states “Projects are initiated to solve problems or satisfy needs”. Thus we can assume that a project success is actually connected to its ability to solve those problems or needs. From the same definition it is apparent that we need an aim or purpose to be successful, i.e. we need a goal. So how do we know that we have reached our goal? We need a way to assess that the goals are achieved. The next question is of course when do we assess? The time of the assessment is linked to the goal we have set. If a goal is linked to the total time or economy of a project, a post-project evaluation is ok (Samset, 2010). On the other hand if you want to assess goals concerning the process of the project then a interim evaluation is more suitable. The timing of the assessment is closely linked to the learning potential, if you want to change the process then the assessment must be made so its possible to try out the changes. Jerrard and Hands (2008) point out problems in trying to create design audits vs. traditional metrics. The design audits should consist of both quantitative and qualitative data, and view both social and economic measures, while traditional project metrics consist of quantitative economic measures.

Even though a failure can be explained as the lack of success Meland (2000) points out important failure predictors in the design process of AEC projects. Important predictors were lack of support from the client, but also design manager´s lack of managerial skills, especially regarding communication, goal setting and planning.

The learning potential of the AEC industry has been debated by several authors and also in the Lean community (e.g. (Christensen & Christensen, 2010; Lantelme & Formoso, 2000; Skinnarland & Yndesdal, 2014). Learning barriers has been mentioned as a challenge for change. Skinnarland and Yndesdal (2014) points out problems with unlearning, organizational structures and norms as barriers of learning. Christensen and Christensen (2010) raise the question of the difficulties of learning because of syntax, semantics and motivation between the trades in AEC projects. Addressing these barriers is important to achieve learning and improvement of the industry.

The AEC industry is a fragmented industry relying on many different actors from the start to finish of the project, creating challenges with communication and teamwork within the AEC projects (Kerosuo, 2015). Bølviken (2012) characterizes the industry´s production as a project production of unique products and temporary organizations. “Temporary teams function under constraints off high uncertainty and interdependence during a limited time. The functionality of the teams is dependent on their members’ sets of diversely skills and knowledge sets”(Kerosuo, 2015). Emmitt and Ruikar (2013) states “Building design is rarely the product of one persons thinking process; rather it is the result of many different disciplines collective knowledge.” The performance of the design team is thus dependent on the group members’ skills and knowledge, and their ability to work as a team. Svalestuen et al. (2015) list 12 key elements that influence the performance of a building design team. As table 1 shows, the survey indicates that trust between team members and commitment to the project is the most important element for an effective team. However, a team is not build on trust and commitment alone. The other elements are also important in order to create an efficient building design team. Having a team building exercise is important in the design phase were team members are unfamiliar with each other, and even a short exercise to commit them to the goal is always a good investment. Furthermore, focus on team development throughout the process is important as it takes time to form a team (Svalestuen et al., 2015).

Table 1: Key elements of a good design team (Svalestuen et. al., 2015)

Elements	Average score	Short explanation
Trust between the team members	1.34	Honesty, transparency, consistency and respect
Commitment to the project	1.34	Involving team members in planning
Involvement in the goal setting process	1.56	Commits the members to the goal
Good collaboration between all project leaders	1.56	Increase collaboration in the whole project
Cohesion	1.72	Commitment to the team
Contract models	1.78	Needs to encourage collaboration
Elite feeling	1.88	Create a unique and challenging project
Team building	1.94	Getting to know each other and the project
Former relation between team members	2.03	Speed up the team building process
Identifying the design team members' roles	2.06	Team composition
Focus on team development	2.22	Takes time and effort to form a team
How difficult the goal is to reach	2.66	Effects the elite feeling

Managing the design process is challenging due to the nature of design (Knotten et al., 2015). The design management can be divided in two parts, the management of the process and leading the design. The management is trying to keep the process on time, at budget and with the right quality. The design leader is trying to get the most of knowledge and creativity of the team. The high flow of information, and the need of decisions call for a strong collaborative environment. There have been some efforts to describe ways of collaborative design management (e.g. (Emmitt & Ruikar, 2013; Fundli & Drevland, 2014)). Fundli and Drevland (2014) highlighted the importance of a start-up meeting in the project. A start-up meeting with the project team had positive effect on cooperation, communication and commitment of the team members.

The Balanced Scorecard (BSC) is a common method to align strategic, operational and tactical goals. "The BSC should translate a business units mission strategy into tangible objectives and measures" (Kaplan & Norton, 1996). There are four focus areas in the BSC approach, the financial focus, the customer focus, the internal business processes focus and the learning and growth focus. "The measures are balanced between the outcome measures – the results from past efforts and the measures that drive future performance"(Kaplan & Norton, 1996). The BSC looks at measurements of what has been e.g cost, time, but also at what to come. It also balances between external and internal focus (see Figure 1). The BSC can also be use to set the strategic goals. The focus here is; Clarifying and translating the vision and strategy. Next is communicating and linking these. After that planning and setting the targets, and finally giving strategic feedback and learning.

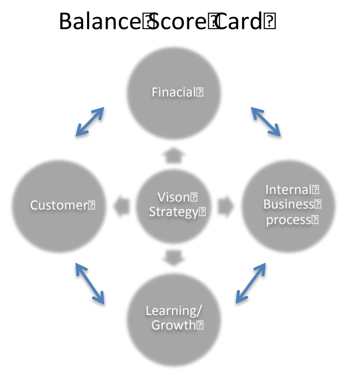

Figure 7: Balanced Score Card

Construction industry has developed a large number of KPI`s (Key performance indicators) and despite the claims about their usefulness they received a fair amount of criticism from many researcher (e.g.(Beatham et al., 2004; El-Mashaleh et al., 2007)). The KPI`s are designed not to give insight into the means of improving performance and therefore have limited use for internal management decision-making (Bassioni et al., 2004). KPI`s are `lagging` measures (Haponava & Al-Jibouri, 2012). They are used for review purposes after a completion of the project and do not provide the opportunity during the project development and execution stages.

FINDINGS

When introducing Mutual Assessment (MA), the contractor primarily aimed to increase the client satisfaction of projects by addressing issues raised by the client (and others) during the project instead of post project evaluations. This works because if the client does not raise any issues during the project, how can the client then raise issues at the end of the project. Hereby, the contractor can avoid client dissatisfaction.

MA consists of two major parts, the planning of MA and the execution of MA. The planning of MA needs a consensus from the team members and the client to use this method. The planning is done collaborative in a start up session. In the planning one needs to agree on the use of metrics, how often to asses, who will evaluate on behalf of who, and of course to agree on the common goals of the project. The start-up session has many agendas to cover, but in regard of MA the most important is to agree on when the team wants to carry out an assessment session, who will answer on behalf of who, and agree and what goals are important for our project. The start-up session has two outputs, an assessment plan and the assessment goals. (See Figure 2)

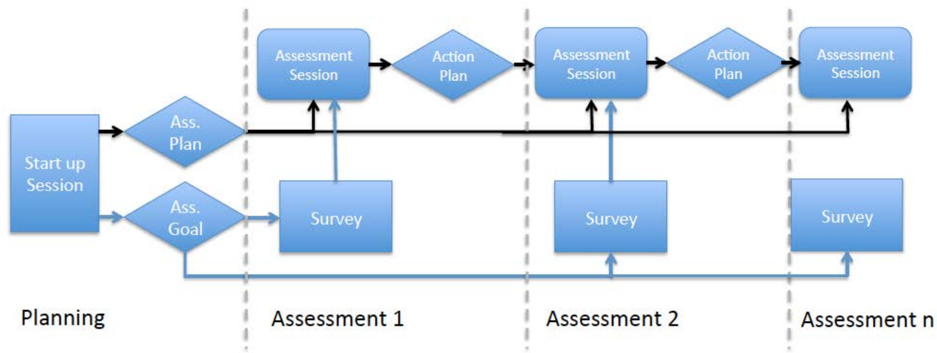

Figure 8: Mutual assessment

The assessment plan consists of two major parts. The first part is to decide who of the team is answering and participating in the survey and the second part is to plan when the assessments should take place. One of the key points of MA is that all of the main parties are to be heard in the assessments. There will of course be a limitation to how many of the involved parties (consultants, suppliers, sub-contractors etc.) should be included, but a rule of thumb here could be to ask yourself how dependent you are of these parties. If a party could be the success or failure of the project, then they should be involved. Together the project should agree on who are the parties to assess each other and who of the projects members should the represent their party. For instance this could mean that the main contractor would point out who of his team would assess the other. The same would apply for the client, architect and the other consultants. A key here is to make a representative voice. For the purpose of not letting the project history cloud the teamwork, it is important that the facilitator of the MA- process have no direct connection to the project. The facilitator leads the start-up session and runs the assessments sessions.

The second part of the assessment plan is to decide when the assessments should take place. Consequently, creating fixed interval between each assessments and assuring that the team members actually reserve time in their busy schedule to improve during the process. This could be a milestone or just fixed intervals in the design phases.

Figure 9 shows an example of a plan for a project. The red lines show the planned assessments sessions. The sessions are placed so the team can benefit from the session and prepare for the next phase. The number of assessment sessions will vary according to what is decided in the assessment plan.

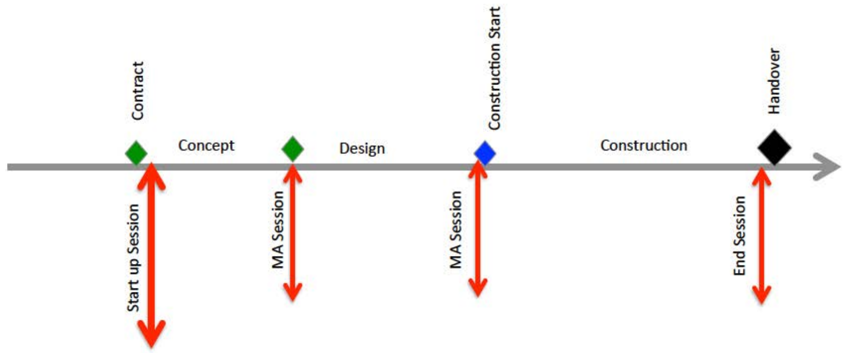

Figure 9: Assessments sessions

The assessment goals are worked out together through the start-up session. The goals are set by the team in collaboration, and are important for this project and this team. The goals will typically be related to cost, time and quality, but also to cooperation, client satisfaction etc. The goals will then be formulated so they can be assessed in a survey. *Figure 10* shows an example of goals from a project, translated into questions. In the survey the questions will be answered as e.g. "how is company N.N. helping to keep the project on plan?"

Questions:

Is the project on plan?
Is the project on cost?
Is the quality as ordererd?
Are flaws and errors taken care of?
Are the responsibilites in the team clear and accepted?
Is the cooperation based on honesty and openness?
Is teh communication open and constructive?
Is the cooperation positive and focused on results?

Figure 10: Example of Survey questions

The second part of MA is the execution of the assessment sessions. The execution should be according to what the team members planned in the start-up session (see figure 2). First, the team members representing the project receive the survey with the pre-agreed questions. The team members will rank the other team members after their ability to fulfil the goals. A low score on several of the survey questions from many team members indicates that there is an issue that deserves attention from the team. Second, the appointed facilitator will go through these surveys and pick the topics that need attention from the team. In the assessment session all the team members should be present, including the client. The facilitator runs through the topics, creating a dialogue for the best way to improve the team. The result of the session is a unified action plan that describes who is responsible for what action and when it should be done.

At the next session the completion of last session's action plan is addressed, and the next MA starts. In the end of the project, the actors arrange an end assessment session that sums up the project.

DISCUSSION AND CONCLUSION

Mutual assessment (MA) is an experienced based approach developed by a Scandinavian contractor in order to improve the client satisfaction with project execution. The contractor works primarily with negotiated contracts and have a yearly turnover of approximately USD 204 million. By increasing the client satisfaction one can assume that the client gets a better product. This is done by focusing on the team and letting the key team members assess each other with interim evaluations throughout the project.

The contractor's experiences from using MA are very good. Since they started using MA, all their projects had a positive financial outcome. They also reported of no conflicts with clients or other cooperating parties.

MA addresses several challenges in the AEC industry. First it addresses the challenge of a fragmented industry working with unique products and temporary workers, by collaboratively making a design team. The collaborative setting – ,established through the start-up session, the planning of common goals and execution – makes the grounds for continuous improvement. All this helps to achieve good design teams(Svalestuen et al., 2015). Second, MA addresses the performance and improves the performance through a collaborative dialogue, which can replace KPIs. Third, MA creates an opportunity for learning during the project, instead hoping that something is learned when the project is finished. By agreeing on MA the actors remove an organizational barrier of learning (Skinnarland & Yndesdal, 2014), and by letting all key team members set goals and evaluate them one removes the barriers between the trades (Christensen & Christensen, 2010).

Involving the team participants is important (see table 1), and the team participants get involved when practicing MA. Tillmann et al. (2014) highlights the importance of a collaborative environment when creating a learning team. This together with a collaborative design management (Emmitt & Ruikar, 2013) or collaborative planning in design (Fundli & Drevland, 2014; Veidekke, 2013), the management of the process is helped.

Lantelme and Formoso (2000) state that one of the most cited approaches to measurement is the Balanced Scorecard Method, introduced by Kaplan and Norton (1996). The MA has some similarities with the BSC, by looking at important goals, both hard and tangible goals, and also to look at more soft measurements of team evolvement and cooperation. By using BSC as a frame for goals and measurement it is easier to make this transparent for everyone.

Even though the BSC was developed for corporate structures, BSC could be aligned to AEC projects (See figure 1). Clarifying and translating the vision and strategy for the project should be done by the key stakeholders, representing goals for the project and how this affects the corporates strategies. Communicating and linking is ensuring that all project members are aware of the common goals of the project. Planning and setting target are the goals the project wants to achieve, made tangible so one can assess them. The goals should represent all the four focus areas of finance, customer (time, cost, quality), the working processes of the project and learning processes of the projects members. This should finally be organized in such a way that the feedback from the process could be assessed and aligned with the strategy. The goals of the projects could be e.g. project finance, the client focus, team process, and learning / development. Kaplan and Norton (1996) highlight the important of linking the goals both in the organizations and at the companies CEO level.

MA fills a gap in design management by letting the whole team assess how they work together, thus contributing to a more thorough continuous improvement of the design team. Getting a good team needs collaboration and good assessment. MA is a versatile approach, which can adapt to different project executions and sizes as long as there is a mutual agreement on the need of assessment.

MA is based on the fact that the project participants are truthfully in the survey and in the assessment sessions. There is a need of trust to make MA work. In small projects with a low number of team participants it might be transparent on a personal level who is assessing who, risking to shift the focus away from the continuous improvement process.

MA was primarily set up to increase client satisfaction and the authors see some room of improvements. By structuring the goals of the project through a framework based on BSC one can better align project goals with the team. Because of the fragmented nature of the AEC industry, MA is an important tool of continues improvement of teams, even if a client does not want to be a part of MA.

The involvement, collaboration and the aid of process control makes MA an approach well suited for Lean Construction approaches, and the learning loop of LPDS.

For the contractor MA has proved to work well in the design phase. The authors believe that the approach could work equally well in all the phases of an AEC project, and in fast track projects in particular. Further research would be to test the MA approach in more projects, and also to expand on the number of interviewees. It would also be interesting to map other construction companies' experiences from using MA approach.

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BENEFITS REALISATION: AN INVESTIGATION OF STRUCTURE AND AGENCY

Michail Kagioglou[1] and Patricia Tzortzopoulos[2]

ABSTRACT

The last 3 decades have seen significant developments in all aspects of process management and New Product Development (NPD) in the Built Environment. Many of the characteristics of NPD models have been challenged and new key principles are emerging as necessary for success. The issue of delivering benefits rather than just tasks and processes has become more prominent also.

Previous work related to NPD and Benefits Realisation has focused on the representational and process aspects of their implementation. This paper extends these notions and in particular introduces and explains ‘structure’ and ‘agency’ as they are understood in social sciences. In particular the notion of ‘structure’ will be presented as part of the overarching imperative for action and the actors involved in both undertaking and enacting processes.

Finally, the paper concludes in describing how research should be undertaken within the particular context of benefits realisation. The Unique Adequacy (UA) requirement of methods is critical in researching benefits realisation. As such, researchers need to be competent (in theory and practice) of and in the context, which they investigate. Implications for future research are also identified.

KEYWORDS

Benefits realisation, structuration theory, value, process, new product development.

INTRODUCTION

The area of NPD has been highlighted as a key competitive force for any organisation. Within the Built Environment in general and in construction more specifically NPD has been investigated form a number of perspectives, all of which aim to optimise the process of NPD and deliver ‘value’ to customers, both internal and external (Kagioglou et al. 2000). Recent changes to NPD processes over the last 15-20 years have primarily focused on sequencing or structure of activities (Cooper 1994; Cooper and Sommer 2016), the timing

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of activities in relation to stakeholder involvement as well as broadening the scope of the process as it is understood by different groups. This paper briefly presents these developments and extents the traditional view of NPD to that of Benefits Realisation Management (BRM) as a means of ensuring that overall project and programme benefits are delivered consistently. Much of recent research has focused on the representation of NPD and BRM processes with some understanding and incorporation of change. The theoretical foundations for how change and process representations co-exist is not very well understood. The paper introduces the structuration theory, which originated in social sciences as a potential candidate in providing the theoretical foundation for enacting NPD and BRM processes and how 'duality' of process and action is paramount for the future rather than the narrow and flawed current 'dualism' paradigm.

NPD IN BUILT ENVIRONMENT AND CONSTRUCTION

NPD can be defined as (adapted from Kagioglou et al. 2000): The process by which an outcome (tangible and/or intangible) is produced to satisfy a (implicit or explicit) need/want as identified by a customer (individual, group or stakeholders groups) through the planning and organising of resources (human, capital, financial, etc.). There are many different models of NPD that have been produced all of which have embedded within them both implicit and explicit logics and philosophies. This section briefly describes their main characteristics and progress made in each area.

WHAT IS THE STARTING AND FINISHING POINT?

The starting and finishing points of NPD processes are largely dependent on the context within companies use them. For example, in construction where the client procures a building NPD processes normally start form pre-procurement and contract award i.e. feasibility/concept development to the delivery and handover of a building. Hence, this project focus of NPD processes (endemic in construction) is designed to accommodate the project delivery. Typical examples of such processes include the RIBA plan of works prior to 2013's version (www.ribaplanofwork.com), which has been prominent in UK construction for decades.

Over the last decade or so more holistic NPD models have started to be developed which aim to accommodate two important issues. The first is to recognise that projects and programmes are there to deliver change and fit around an overall business model and strategy with expected results. As such, issues of strategic intent, business model development, feasibility aspects have started to be developed which do not assume that a building is always the right answer to a specific business need. In doing so, a more thorough investigation is necessary to examine all options. On the other hand, at the end of a project the whole aspect of operations, maintenance and decommissioning are making their appearance as part of a drive to consider whole life costing issues, sustainability, operational costs vs. capital costs, etc. The latest revision of the RIBA plan of works (www.ribaplanofwork.com) is a great example of how such issues should be considered. 'Seeing the whole' NPD processes are now prominent.

WHAT IS IN AND WHAT IS OUT?

The content of NPD processes in terms of what needs to take place and at what stage is also different. There is a proliferation of models, which include anything from 6-7 steps to more than 30. There is still an apparent confusion about what is the purpose of an NPD model, at what level of the organisation is used at e.g. senior management, portfolio and project reviews, etc. and therefore there are still operational processes that are looked at and considered as strategic and vice-versa. This distinction can have significant implications, especially for repeat clients and those organisations that are interested in overall system improvements time after time.

INTERNAL LOGIC AND 'SPIRIT' OF NPD PROCESSES

There are two key distinctive characteristics that can exemplify the logic of NPD processes and identify their 'spirit'. The first characteristic has to do with how different stages and phases are enacted in the process. For example in traditional processes e.g. waterfall models, the stages are distinct form each other and followed the traditional over-the-wall approach. To resolve the 'over the wall' deficiencies NPD processes developed in two ways. The first had to do with overlapping stages and the second with progressive fixity deliverables or outcomes. In the former case, the notion of 'fuzzy or overlapping stages was introduced (Cooper 1994) where instead of handovers between stages (some) activities are allowed to overlap stages so that other activities from subsequent stages can be initiated. This approach has proved to be popular and it manifested in various ways in different models. For example, it helped the planning of the 'fuzzy' front end of design processes where there is still much ambiguity about what needs to be realised and through which schemes (Cooper 1994). It also forced projects to bring about specific expertise and actors in the process together to provide more complete solutions.

The second aspect of progressive fixity enabled activities to 'exist' through stages and develop incrementally until either a full solution has been identified or the best solution up to that point has been identified with the former being a measure of satisfaction the latter being a compromise. Both are valid approaches for different reasons.

FORMALITY VS INFORMALITY

The area of formality or informality of processes is very important. There is normally an implicit assumption that formality relates to large and complex organisations and informal to small and fairly straight forward organisations/projects. This might indeed be the case in most circumstances. Cooper and Sommer (2016) have recently introduced the concept of agile stage-gate hybrid models where they identify, briefly, when each model should be used. For example, they claim: agile fits better when 40%-70% of final design parameters are defined prior to development, whereas it requires more that 90% in formal/traditional processes; when the product specification is established in general, upfront agile works best as opposed to when it is established in detail where formal processes work better, among other features. In terms of the overall approach Cooper and Sommer (2016) also identify agile as an evolutionary process based on frequent design-build-test iterations, milestone releases and beta versions with actual customers, continually reprioritising features. Traditional but efficient phase-gate processes are well defined with clear entry/exit criteria, explicit tasks and deliverables and rigorous checkpoint review meetings and monitoring happening according to plan.

PLANNING AND/OR ORGANISING

Johnson and Brennan (1996) in their seminal paper state that " …the widely held but conceptually flawed motion that activity proceeds via the implementation of plans, informs the idea that a strong causal connection between management and goals and operational activity can be established through representation and plan generation." They go on to state/highlight that " From the manager's point of view adoption of the management-as-organising approach may be accompanied by a feeling of loss of control because a tight coupling between management goals and operational activity is denied. However, we have argued that such a coupling is not feasible and therefore the feeling of control engendered by the management-as-planning approach is largely illusionary." Indeed, they use Lean Manufacturing as an example of management-as-organising "…where the systems are largely reactive and production scheduling relies on the structuring of the physical environment rather than the planning environment of the teams." Dant and Francis (1998) have also looked at the issue of planning and suggested an interactional approach to planning in organisations by comparing and contrasting the relevance of the rationalist and the contingent models of planning concluding that "…neither model is adequate to describe the process of planning activity which is always a practical and situated activity whose character emerges in the process of interaction." Therefore, it is quite clear that the role of NPD models has some representational value, which can lead to planning activity, which however does not constitute action. Activity is situated and therefore can only be understood through the impact of agency. The paper expands on this issue by considering at structuration theory and Benefits Realisation.

OUTPUTS VS OUTCOMES

In addition to the flawed assumption that planning equals action and that causality exists between management and operational activity, there is an equally flawed assumption that project plans deliver outputs and outcomes. This flawed assumption exists at two levels. At the first level there is the whole contested area of project success (Serra and Kunc 2015) and what actually translates to with the – appropriate – criticism of the traditional project management practices (Koskela and Howell 2002). At the second level there is the implied assumption that the delivery of a project will automatically deliver the required business outcomes. It is very important to stress that any NPD process will need to look at the relationship between project outputs and outcomes and fuse the two as part of an integrated whole. Reiss et al. (2006) emphasize that there is a path from projects to benefits: projects have outputs and the combination of different outputs generates the capabilities that enable the desired benefits to be achieved. According to Maylor et al. (2006), without the effective transition from outputs to outcomes, products and services remain only capabilities, or potential sources of benefits.

KEY PRINCIPLES FOR NPD PROCESSES

The discussion up to now has highlighted a number of areas that are pertinent when considering NPD processes as representational models and maps which can guide projects through to completion as well as the embedded thinking in these models and how they specifically relate to organising and action towards delivering outcomes. It is possible therefore to identify the following as key principles for an NPD process:

1. Seeing the whole – from cradle to grave
2. Customisable / flexible and consistent of its principles
3. Progressive fixity of activities
4. Coordination / Orchestration of process (linking planning to organising)
5. Organises actors for delivery and synthesising the knowledge base
6. Feedback loops and learning
7. Aiming to realise project/programme outcomes and benefits

The following sections will expand on point (7) and also introduce the theory of structuration as a means of explaining and articulating the conceptual/theoretical bridge between NPD process representation and realisation.

BENEFITS REALISATION MANAGEMENT

Benefits realisation Management (BRM) is defined by Bradley (2006) as: an outcome of change, which is perceived as positive by a stakeholder. Breese (2012) locates the BRM growth to the growth of change management and also performance management paradigms in management studies. The approach assumes right form the outset that coordinated action can introduce a sense of causality between action and outcome, which can be predictable. This need for predictability arose from the failures of many projects and some argue of project management in general, to deliver strategic benefits (Mir and Pinnington 2014; Badewi 2016). It is within this framework that traditional approaches to delivering on cost, time and quality become obsolete both as concepts and also as practice. BRM aims to bridge link between defined strategic benefits and project/programme management.

Tillmann et. al., (2009) identified the following reasons for the need for BRM:

1. Vagueness of benefits definition, tracking and allocating responsibility for delivery
2. Definition of client and stakeholder groups as well as their influence on the realisation of benefits
3. Long delivery timescales involved between benefits definition and realisation
4. Lack of making explicit identifiable interdependencies
5. Lack of explicit and correct actions taken to manage change

Although BRM was designed to accommodate the above deficiencies, it is argued by Breese (2012) that because it is located within the 'modern paradigm' of management science, it has seven supporting themes as identified by Darwin et al (2012) and adapted below:

1. Logic: assumption that by planning a good outcome it can automatically be realised
2. Linear Thinking: one activity leads to another over the duration of the project/programme

3. Quantification: this follows the notion that if it cannot be quantified it does not exist. Quantification is critical to evaluation
4. Cause and Effect: causality can be pre-determined
5. Reductionism: some benefits and impacts can be more 'valuable' than others
6. Split between thinking and doing: planning vs. organising split
7. Control: the appraisal process is a means of exercising management control over resources

Tillman et al. (2009) has identified eight models of benefits realisation and Sapountzis et al. (2010) have also developed a BRM model called BeReal which is making more explicit the link between change, benefits and organisation for delivery as well as suggesting the organising functions necessary to deliver relevant plans (Sapountzis et al. 2011).

This paper locates NPD as the overarching process by which strategic and business benefits come together for realisation through the delivery of a product or service. In doing so, it also positions BRM as an integral part of the NPD process in linking strategic benefits to realised products and services. There are still though significant issues that need careful consideration in relation to what and how NPD and BRM processes work within the spectrum of planning and organising. Project management practices should consider projects situated in a social and political context, adequately dealing with the dynamics of this context, the complexity of social interaction and human action and the framing and reframing of projects within an evolving array of social agenda, practices, stakeholder relations, politics and power (Winter et al., 2006).

Rooke et al. (2010) also identified the problem of value associated with Lean knowledge management within the BRM framework. Expanding from this position the 'value for who' question sits at the heart of BRM which is defined through a process of negotiation and evaluation through human action. It is this difference between what Breese (2012) calls the 'modern paradigm' of management and the 'real world.' In doing so he concludes in the study of regeneration programmes that "…demonstrated that where the assumptions of the scientific approach of the 'modern paradigm' underpin the management framework there will be tensions and conflicts, because the assumptions do not hold in 'the real world'. The consequence will be that benefits management (and also related aspects of project management, such as value management) will be played out in an ambiguous and contested manner, reflecting the roles and actions of the different stakeholders, how will vary in the degree of power and influence they wield." He also states that "There is a need for theories of BRM to be developed which are based on in-depth analysis of practice and acknowledge and incorporate ambiguity and uncertainty.' The inevitable issue raised here is that in many situations there is very little scope for an objectively defined 'best option' rather the ones exist are relative and mediated through human action.

STRUCTURE AND AGENCY

The paper demonstrates two critical aspects. Firstly, that Benefits Realisation as a Process sits within the realm of NPD and therefore is bound by some of its characteristics, and secondly that a simplistic process-view of NPD and BRM (as a meta project management process) is not enough to explain and incorporate the dynamics of both situational technical and non-technical choices and expressions of value. Therefore, both representational (hard view of process) and perceived (soft view of process) aspects need to be considered.

The notions of structure and agency have been considered extensively in the realm of social sciences (Giddens 1984; Sewell 1992; Chouinard 1997.) Initial views of structuralism and functionalism have tended to follow an objectivism paradigm. Functionalism tended to look towards biology as the science that is nearer to social sciences whereas Structuralism rejected evolutionism and biological sciences. However, both of them strongly emphasised the pre-eminence of the social whole over its individual parts (Giddens 1984). Further developments in social sciences constituted 'structure' as one of the most elusive terms on social sciences (Sewell 1992). In traditional discourse on structures, change is located outside of structures. In doing so it emphasises the priory of structure (or culture as it is understood in many writings) over agency. In such a way it becomes deterministic in nature and very rigid. Structure and agency exist as a duality i.e. two parts existing in isolation with some relationship between them. Giddens theory of structuration (1984) has been introduced as an alternative to these rigid views and it aimed to reject structural determinism through constant emphasis on the interplay of structure and agency, offering a broader conception of social power as the outcome of struggle over allocative and authoritative resources and recognises the significance of spatial organisation in the structuration of social relations (Chouinard 1997).

THEORY OF STRUCTURATION

The theory of structuration was introduced by Giddens and broadly speaking it has some of the following characteristics (Giddens 1984):

- It suggests that the basic domain of study of the social sciences is neither the experience of the individual actor, nor the existence of any form of societal totality, but social practices ordered across space and time
- It accepts a hermeneutic starting-point in recognition that the description of human activities demands a familiarity with the forms of life expressed in those activities. It is the reflexive form of the knowledgeability of human agents that is most deeply involved in the recursive ordering of social practices.
- The reflexive monitoring of activity is a chronic feature of everyday action and involves the conduct not just of the individual but also of others. Therefore, actors not only monitor continually the flow of their activities and expect others to do the same for their own, but they also monitor aspects, social and physical, of the contexts in which they move.
- An ontology of time-space as constitutive of social practices is basic to the conception of structuration, which begins from temporality and thus, in one sense, 'history'
- Structures do not exist concretely in time and space except as "memory traces, the organic basis of knowledgeability" (i.e., only as ideas or schemas lodged in human brains) and as they are "instantiated in action" (i.e., put into practice).
- Rejects Dualism (separate parts in a system, broadly speaking) and adopts duality whereby structures are not brought into life by social actors but they are continually recreated by them via the very means by which they express themselves as actors. In

and through their activities agents reproduce the conditions that make these activities possible.

- Structure is not to be equated with constraint but is always both constraining and enabling

DISCUSSION AND CONCLUSIONS

The paper started off by reviewing progress made over the last few decades in NPD and arriving at a set of key principles critical to its success. Ultimately the success of NPD processes is defined by the degree to which envisaged benefits are delivered (outside of the traditional metrics of time-cost-quality which are narrowly defined).

The paper identifies the degree to which planning alone is adequate in realising outputs and it is shown that planning alone is simply inadequate. Human action/agency is critical in organising around project, programme and NPD delivery. Aspects of agility, progressive fixity, coordination, learning and delivery cannot be thought of, let alone realised, without the impact of human agency. Therefore construction processes have to be designed with this in mind, ensuring that representation and action are tied in together. The impact of such considerations can result in establishing, for example, acceptable levels of change of plans without penalty clauses, new forms of contract to evolve and closer consideration of collaborative project practices being established.

The theory of structuration identifies and promotes the dualism of structure and agency and that actions constitute structure which itself is constituted by the actions taken. Therefore, it rejects the dualist paradigm and adopts dualism as the modus operandi. The implications for theory and practice are significant. Firstly, it forces researchers to look at theorising around change and process concurrently rather than in isolation, together as one rather constituting the sum of the two parts. NPD and BRM processes should possibly be designed not only to accommodate change but also to effect change so that they can be reformulated as a result of this emerging change. In practice the implications would be that checks are put in place to ensure that 'fixed' solutions are 'opened up' and being re-validated, hence embedding a culture of continuous improvement rather than striving towards fixity as early as possible. Toyota's set-based design (fixing sets of attributed and solutions rather than whole systems) NPD process is starting to demonstrate this aspect to a moderate degree (Morgan and Liker 2006.) Significantly, the rate of change and the insistence of measuring benefits based on initial requirements should be, largely, rejected. Could the same apply to initial client requirements, specifically when long timescales and in-experienced clients are involved? This area can have significant implications on how project and programme success is measured, in that benefits need to be tracked continually and post-project and post-occupancy evaluations change their focus from measuring what was originally conceived to what have emerged through practice in NPD. The implications for how infrastructure policy (say in social housing, regeneration, health and schools programmes, etc.) is evaluated and measured are also significant.

Any notions of process representation alone are not enough to evaluate success. In relation to this Rooke and Kagioglou (2007) identified the need to consider the Unique Adequacy (UA) requirement of methods needs to be extended to researching NPD and

BRM issues whereby the researcher (and arguably practitioners also) needs to be competent (in theory and practice) of and in the context which is investigated. The research methods themselves also can only be determined through considerations of context and created within that context. Lean Construction's recent progress in production management and control can be examined around these new lenses which requires further research, in particular how considerations around time-space can be examined through the structuration theory.

The authors have introduced the structuration theory as a candidate for consideration when investigating the theoretical foundations of the interface between NPD, BRM and Project Management.

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DEVELOPMENT OF AN EXPERIMENTAL WASTE FRAMEWORK BASED ON BIM/LEAN CONCEPT IN CONSTRUCTION DESIGN

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ABSTRACT

The construction industry faces many problems and challenges especially with the construction of housing which are due to the high level of non-value-adding activities (waste) that reduce the overall construction performance and productivity. In recent years, there have been investigations and research on improving the performance of construction. Lean construction is widely known as an effective process which aims to maximise customer value and the efficiency of the project by eliminating non-value-adding activities or waste. Moreover, the Building Information modelling (BIM) concept has been recognised as a collaborative process which aims to improve the overall project performance through its tools' capabilities. This paper intends to study the potential effects of integrating these two concepts in order to reduce construction waste.

This paper presents a framework, named an Experimental Waste Framework based on the findings of this paper to explore how an integrated BIM and Lean concept can contribute to the practicable reduction of construction waste in the design process of construction.

KEYWORDS

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

INTRODUCTION

The construction process can be found as an inefficient process in which a very high level of waste (non-value added) activities exist. Horman & Kenley (2005) conducted a meta-analysis of time that is wasted in construction activities which revealed that over the past 30 years, an average of 49.6% of construction time was wasted in activities that add no value. Non-value-adding activities will have negative impacts on the construction industry in terms of inefficiency and low productivity. Moreover, technological adaptation is another major issue as the construction industry is lagging far behind other industries when

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it comes to adopt new technology (Flanagan, Ingram & Marsh 1998; Hewage et al. 2008; Government Construction Strategy 2011). Lack of modern technological implementation will result in dissatisfaction of workers which will accordingly contribute to inefficiency of projects in terms of communication and information transfer (Hewage et al. 2008; Bowden et al. 2006).

Despite the fact that the construction industry faces major problems, the industry is still likely to overcome some of these major key challenges by implementing effective approaches and processes such as Lean Construction and Building Information Modelling (BIM). In order to achieve effective change as well as improving efficiency of the construction process Egan (1998) recommended adoption of Lean principles. However, in construction projects there are some difficulties to implement Lean because of the complication of construction tasks and factors in its different stages especially in the design stage. It is widely believed that using a 3D modelling software and process (BIM), which will help all project participants to visualise the whole construction process early in the design phase, will enable Lean principles to be used in construction projects (Eastman et al. 2011, 297-300). Also, implementation of BIM can have significant benefits to the construction industry in terms of increasing productivity and quality and reducing cost as well as project delivery time which will result in better project performance improvement (Eastman et al. 2011, 297-300; Azhar 2011).

As stated by Sacks et al. (2010) “there is a lack of systematic exploration between BIM and Lean construction” to discuss the benefits of these two collectively. Also, the existing literature on the integration of BIM and Lean construction are more focused on the ‘theoretical framework’ which explores the “degree of validity of the interactions” (Sacks et al. 2010) and not their practical applicability to eliminate waste. Therefore, there is a need for research to bridge this gap in knowledge by using existing evidence on both BIM and Lean construction principles and explore some practicable solutions to reduce waste in the design process through an integrated Lean/BIM concept to rethink the internal construction processes.

INTERACTION OF LEAN AND BUILDING INFORMATION MODELLING (BIM)

SYNERGY BETWEEN LEAN AND BIM

Lean principles can better contribute to eliminate waste if they are adopted with another concept which facilitates waste reduction. BIM can be recognised as the beneficial concept which will help reduce construction waste by the different features that it provides (Sacks et al. 2010). Dave, Boddy & Koskela (2013) stated that “Lean construction and BIM have significant synergies, and can bring benefits if implemented together”. Likewise, according to Eastman et al. (2011, 298) “There is a strong synergy between lean construction and BIM” as some of the principles of lean construction can be fulfilled by using BIM and it will also enable achievement of other principles (Eastman et al. 2011, 298; Sacks et al. 2010). Also, BIM “improves workflow in the construction process” which helps in the reduction of construction waste (Eastman et al. 2011, 298).

The integration of Lean construction principles with BIM can benefit the construction industry by the support and good understanding of the theory of production in construction (Sacks et al. 2010).

BIM is about people, processes and technology (Arayici et al. 2011). However, there is a lack of theoretical evidence on the BIM concept which could support and ensure its implementation. On the other hand, the foundation of Lean construction is based on the theory of production (Koskela 2000) and it is people and process focused.

Therefore, BIM with its technology capability and Lean with its theoretical foundation can complement each other for a better project efficiency. This integration of Lean and BIM is shown in Figure 11.

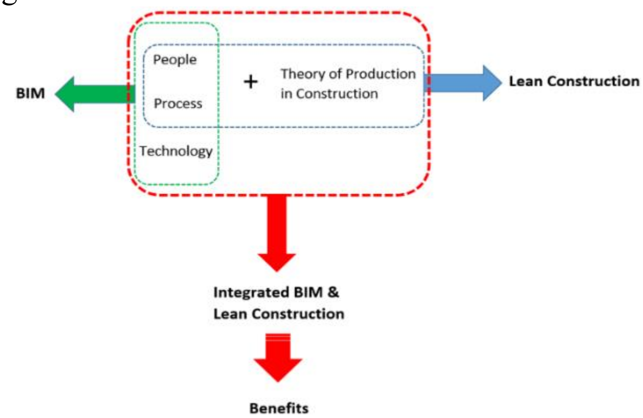

Figure 11- Integration of BIM and Lean Construction

Impact of Lean/BIM Concept on Waste Reduction in the Design Process

Even though all stages of construction contribute to produce waste (Osmani, Glass & Price 2008), the most significant cause of waste is related to design changes (Faniran & Caban 1998) which occurs in the design process. Therefore, it is important to understand the benefits of Lean/BIM integration in the design stage in terms of reducing waste.

Some of the benefits of using an integrated BIM and Lean approach in the design stage of construction were summarised by Dave et al. (2013): reducing the design development life cycle, reducing rework, increasing the number of iterations for value improvement, improving predictability of investment and lifecycle costs (4D scheduling), and enhancing the ability to engage with stakeholders. One of the main beneficial features of BIM is the ability to provide 4D models and simulation, which includes not only the 3D model but also time and cost scheduling, throughout the design process (Eastman et al. 2011). Therefore, if there is any conflict, error or confusion, these issues can be resolved in the design process which will help to eliminate the waste of processing, correction and waiting (Sacks et al. 2010).

Moreover, Formoso et al. (1998) listed three principles for waste elimination in the design process:

Reduce uncertainty, which can be found as one of the main causes of rework. This can be done by increasing the effort in terms of clearly defining the project restrictions and the requirements of internal and external clients;

Reduce waiting time by decomposing adequately the design tasks so that they can be properly planned, and also allow the transfer of information to be made in smaller batches;

Reduce the effort needed for information transfer through team work, and by rearranging the design tasks.

All these three principles can be achieved through the Lean/BIM concept. As all the information is available in a BIM model which can be collaboratively shared between all projects teams, the effort for data transformation will be reduced and this in result will contribute to reduce waste of waiting, unnecessary movement, defects and excess inventory.

METHODOLOGY

The research strategy that is chosen for this paper is Design Science Research (DSR) approach. The research question is certainly important in order to find an appropriate research strategy (Yin 1994, 2013). In this paper the main question is “how an integrated BIM and Lean approach can contribute to waste reduction?”. This research question is related to the field of production management and Information Science; it is also a practice oriented question in nature. DSR is not only used in the field of information science research, but also it is increasingly applied in the realm of construction management (Rocha et al. 2012). In this research method, the key task is to construct an artefact that will be used to develop applicable solutions which address the real-world problems (Hevner et al., 2004; Hevner & Chatterjee 2010). Therefore, DSR can be found as a relevant research strategy for development of a 3D model which aims to find solutions to solve the construction’s problems that are recognized as ‘waste’ in this context.

The research techniques, which have been used in this paper are adopted from ‘*the general methodology of design science research*’ developed by Vaishnavi & Kuechler (2008). The implementation of DSR comprises of five steps in relation to the objectives of this research.

The first two steps of the research process include collecting secondary data through literature reviews on the identification of existing waste in construction and identification of waste through the integration of BIM/Lean. The step three of the process plan includes conducting semi-structured interviews, questionnaires and also developing a 3D model in which the proposed methods of waste reduction, identified in the literature review, interviews, and questionnaires will be applied. Interviews are chosen as another research technique at step three because theories (or suggestions) can be tested through interviews as well as identifying variables and their relations (Cohen & Manion, 1997 cited in Gray, 2004) to collect qualitative data. Six interviews have been conducted in this research. Participants were divided into three groups of: Construction managers, Lean and BIM experts, and Construction Academics. The data that has been gathered from step three was analyzed and evaluated from a BIM/Lean perspective by utilizing the created 3D model. Finally, at step five all the results and data from the previous steps are collected to propose a practical framework which is validated through a set of questionnaires.

FINDINGS

BIM MODEL

The findings of this paper indicate that there are four main BIM features that have the most positive interactions with lean construction and particularly to the waste reduction approach. These following features of BIM are also in line with the BIM features that were highlighted by Sacks et al. (2010): visualisation, Clash detection, 4D scheduling, and construction sequence planning and collaboration and communication.

The four potential benefits of BIM which were also recognised in the interviews and questionnaires, were analysed through a BIM model as part of data collection to demonstrate their potential benefits in terms of reducing four particular types of waste in an experimental practice.

The results indicated that all of the mentioned BIM features will have positive influences on reducing construction waste. For example, visualisation as a key feature of BIM enables the project owner to obtain a better understanding of what the final building will look like early in the design process. Therefore, if the client decides to make any changes to the building design, these changes can be applied in the initial stage of the design process which will have a significant impact in reducing all four types of waste. Visualisation also helps to realise and identify any missing information or elements as well as identifying any design error in the designed building as shown in Figure 12. This will allow the project participants to take necessary actions in order to resolve any identified issues early in the design process which as a result will help to reduce major types of waste (such as defects, waiting, and unnecessary movement).

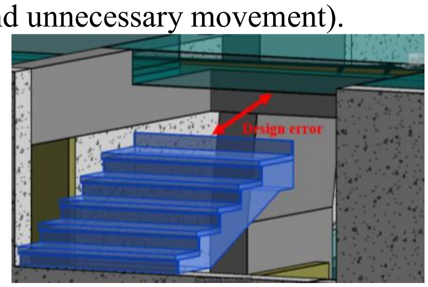

Figure 12 - Design error detection

Also, clash detection as another effective BIM feature contributes to significant waste reduction. Any conflicts can be identified and detected within the clash detection early in the design stage which will help to reduce the amount of time and money that would be spent on discovering and resolving these issues late on construction site.

4D scheduling and construction sequence planning bring design and construction together. Planning the whole construction and design process activities with their approximated duration time will have many benefits to the project in terms of reducing waste. The 4D model provides a construction sequence that will simulate the whole process of construction of the BIM model which facilitates the project team to visualise any specific and critical part of the BIM model at any certain time and date as shown in Figure 13. This function helps to reduce nearly all four types of waste; waiting, unnecessary movement, defects, and excess inventory. Possible failure in the construction sequence can be visually identified which helps to reduce uncertainty before or even during the construction process that will contribute to produce waste later on the project process.

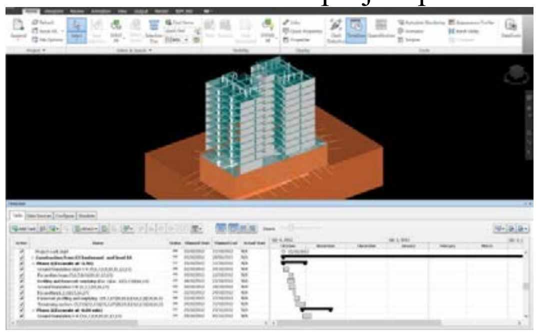

Figure 13 - 4D scheduling and construction sequence planning

Moreover, BIM provides a platform for a better communication through integrated teams in which all project participants including contractors, architects, engineers, and project managers will work collaboratively together. This enables all project participants to visualise and adjust any changes in activities collaboratively together early in the design process which has a significant impact in reducing major types of waste such as waiting, defects, and unnecessary movement.

WASTE IDENTIFICATION AND WASTE REDUCTION APPROACH FROM BIM/LEAN PERSPECTIVE

It was found from all gathered data that even though identifying waste through an integrated BIM/Lean concept is possible, it is also challenging. It was suggested by the interviewees that in order to identify waste in the design process, the root cause of waste needs to be recognised first. It may be possible to recognize the root cause of waste and identify construction waste through both the BIM and Lean concept separately but when these two concepts are integrated, waste reduction approach can be more effective and practical to be achieved particularly in the design process.

There have been different opinions on whether all types of waste can be identified through integrated BIM/Lean concept in the design process. The findings indicate that the four main types of construction waste, which have been considered in this paper, were more likely to be identified through integrated BIM/Lean concept in the design process; waiting, defects, unnecessary movement and excess inventory.

From the findings of all the collected data Table 9 demonstrates the main identified root causes of the four predetermined construction wastes and brief explanations of how they would contribute to producing waste.

The findings of this paper revealed that the waste reduction approach brings many benefits to the design process from Lean and BIM perspective. These benefits are as follows:

Improve the workflow: using the waste reduction approach through an integrated BIM/Lean concept increases the chance of being more reliable and the increase of reliability will accordingly increase the flow of work.

Improve the quality of design: the complexity and uncertainty of tasks will be reduced through the waste reduction approach which will improve the quality of design.

Reduce work load: as all the tasks are clear and the rework is prevented through the waste reduction approach, the overall workload will be reduced.

Value generation: reducing construction wastes which are also known as 'non-value-adding activities' will add value to the whole process.

Saving time: one of the most positive impacts of the waste reduction approach through an integrated BIM/Lean concept in the design process is saving the overall time of the project. The time that would have been wasted on rework, or waiting for one task to be done to start another task, waiting for material arrival or information exchange will be saved.

Moreover, it was argued by both interviews and questionnaires that the waste reduction approach in the design process would overcome some of the construction problems such as cost and time overrun, communication and co-operation, health and safety, and lack of information exchange. However, it was mentioned in the interviews that in order to achieve the benefits of the waste reduction approach in terms of overcoming the construction problems, the BIM model needs to be designed with a high accuracy and the design process must be well-organized as well.

Table 9 - Root cause of waste

Root cause of waste	Construction waste				Comments
	Waiting	Defects	Unnecessary movement	Excess inventory	
Change orders	✓	✓	✓	✓	Change orders would make one task to be done several times. This might have negative impacts on the construction site. Additionally, change orders in the construction would affect the productivity of labour as well as the efficiency of the work.
Decision making	✓	✓	✓	✓	Insufficient design decision making at the wrong time would result in producing major types of waste. Also poor decision making will impact on the construction quality.
Lack of information exchange	✓	✓			Lack of information exchange will make tasks or project team wait for the information to be shared. Also, if information wont be shared at the right time this might result in redoing tasks. Moreover, lack of information exchange might result in receiving wrong information by project team which will result in rework, waiting and reducing the productivity of work and workers.
Poor communication	✓	✓	✓		Poor communication is relatively influence by late involvement of construction management team to give sufficient insight during design stage. This will result in many change orders and poor design decision making which have negative impacts on the project. Additionally, late involvement of project team as a result of poor communication will have many impacts in terms of producing construction waste and reducing productivity and efficiency of work.
Lack of knowledge and the right mind-set	✓	✓			When people who are involved in the project do not have the right mind-set, they would resist to change their working way. This will result in reducing the project efficiency as they would not believe in what they are required to do. Also lack of knowledge will have negative impacts on the outcome of the project.

PROPOSED FRAMEWORK

Based on the findings of this research and the authors' interpretation a waste framework has been designed which comprises five steps as shown in Figure 14. This framework which can be considered as an early attempt to find widely accepted methods, aims to identify waste through integrated BIM/Lean concept in the design process. The framework is developed based on the basis of several aspects of the collected data throughout this paper. Each step of the framework is shown in Figure 15 and Figure 16.

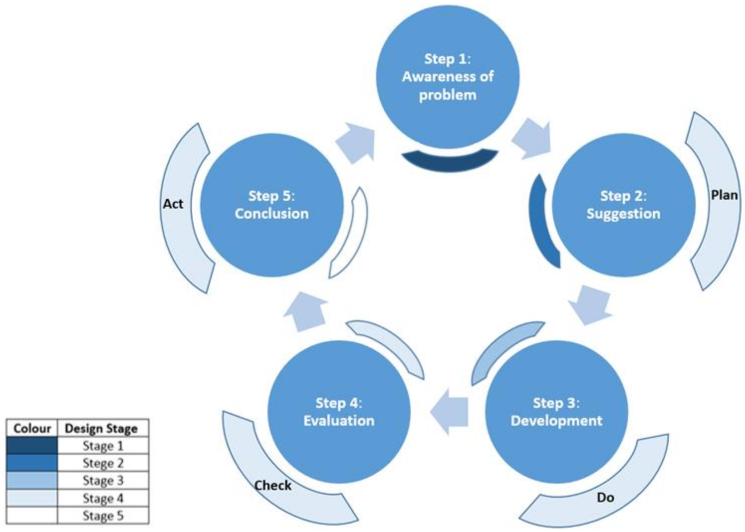

Figure 14 - Proposed Framework

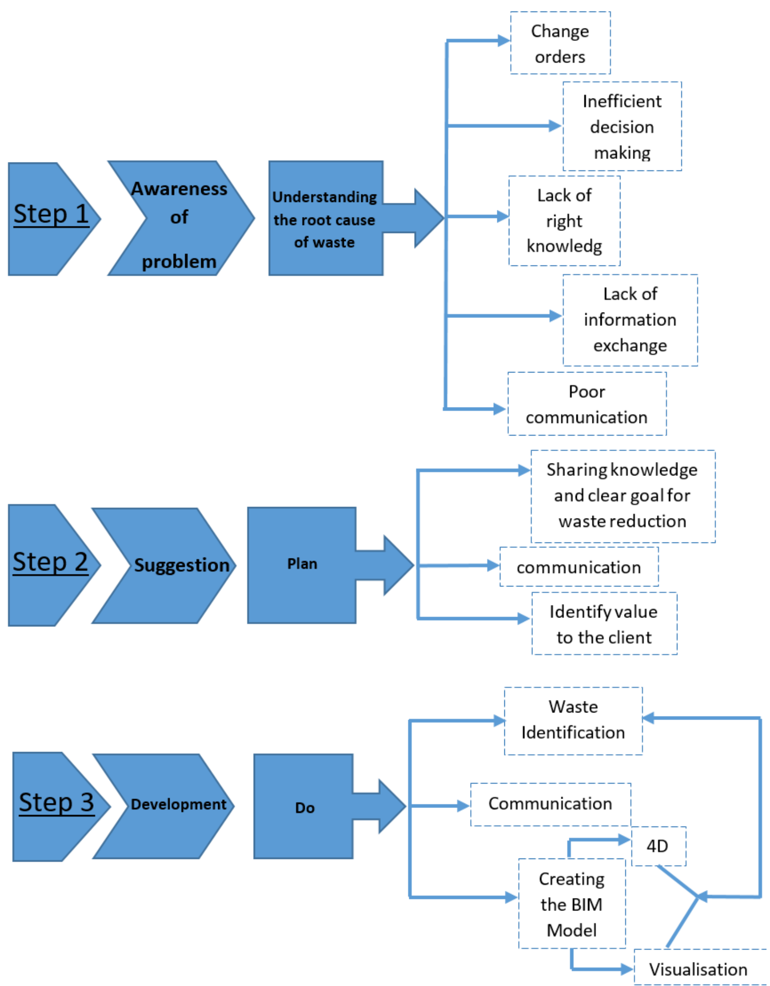

Figure 15 - Step 1,2 and 3 of the framework

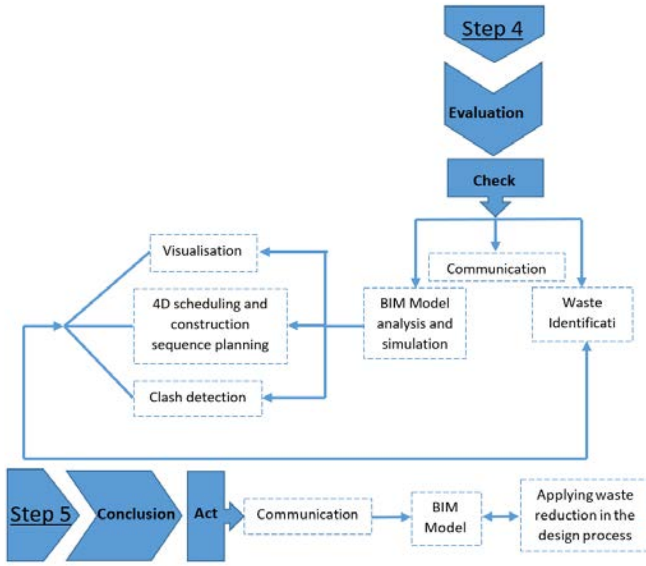

Figure 16 - Step 4 and 5 of the framework

CONCLUSIONS

BIM and Lean concept is widely known in the construction industry and it was found that the integration of these two concepts would bring many benefits to construction in terms of identifying and reducing construction waste. The findings indicated that the waste reduction approach through an integrated BIM and Lean approach would have many potential benefits to overcome some of the construction problems.

This research aimed to develop a practical waste framework, based on the findings of this research from theory (literature review) to practice (interviews, questionnaires, analysing the BIM model), through which waste can be identified and therefore reduced in the design process. The framework was validated through a set of questionnaire that was sent out to the groups of academics, Lean and BIM experts, and construction managers. The 82% of the participants who responded to the questionnaires agreed that the proposed framework will be effective to reduce the waste through an integrated BIM and Lean approach in the design process. The framework should be considered as an initial attempt to find widely accepted methods to identify and reduce waste in the design process.

Further validation of the proposed framework is useful to refine it and make it more effective. Also, testing the framework in a real project and using Delphi technique to know more opinions on it is suggested for the future research. The Experimental Waste Framework still needs to be studied further to propose a long term strategy in which more aspects of waste reduction approach can be addressed not only in the design process but also throughout the whole construction process.

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ANALYSING THE ACCEPTANCE OF CUSTOMIZABLE ATTRIBUTES: A CASE STUDY OF A CONSTRUCTION COMPANY IN FORTALEZA, BRAZIL

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ABSTRACT

Multifamily residential come in standard designs, even though each house buyer has their own social household's structure and lifestyle. Through users' demands, the housing industry is evolving to meet their changes, allowing them to modify specific items on the floor plans during planning phase. The main goal of this research is to investigate the personalization preferences in flexible housing, analysing the acceptance of the standard architectural project proposed by the contractor. This paper analyses a construction company from Fortaleza, Brazil, which builds high-rise residential buildings and offers the buyer the possibility to personalize its unit. The company's customization process is based on Lean Construction principles such as reducing rework, maintaining the continuous flow within construction sites and adding value to its clients, reducing the changes of layout during and after construction. The personalization is either mass customization or a custom-made plan, which is not designed by the contractor and needs previous approval. The research is quantitative and lists customizable accommodations to investigate the extent of acceptance or rejection of each attribute for two residential projects. There were 14 attributes analysed. Eight of them were classified as well accepted (over 80% of acceptance). Nevertheless, four were considered adaptable (within 40 and 79% of acceptance) and only two were not acceptable (less than 40% of acceptance).

KEYWORDS

Process, variability, customization, residential projects, program of needs.

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INTRODUCTION

Within the past 2 decades, the flexibility of real estate units still in the plan phase, for either finishes or spatial arrangement of enclosing constructions, the customization of projects went from a trend to a demand, making differential and competitive factor from the time of purchase and sale of the property.

> "Although housing is part of a specific industry within its own production system, the global transformations influence the evolution of a residential product similarly to products from other sectors. The customization and the widest range of products offered end up being a trend that also hit the real estate industry. (BRANDÃO and HEINECK, 2007, translated by the authors)

Thus, this paper proposes to investigate customization of vertical housing units in a mid-sized construction company from Fortaleza, Brazil. The investigation is limited to quantifying the acceptances, exclusions and inclusions of modifiable attributes within the original plan.

Is there a need to customize one's housing unit, given the variety of residents' profiles in a single residential tower, or is there a particular desire of the client to be different from the others, even though the standard plan meets one's needs? The will to have both questions answered stimulates research, because the construction company of this case study claims the process of customizing an apartment to be complex, mostly considering the impacts on its planning and construction processes.

The relevance of this research may be also justified by some articles that have already been published analysing the process of customizing developed by this construction company (such as Kemmer, 2010 and Rocha, 2013), but none of them addresses the investigations of layouts chosen between by each customer. Those studies focus in detailing the process, evaluating the costs and its implications, listing any difficulties or business developments and confronting the customization as a marketing strategy and the company's management philosophy (lean construction). Thus, among the universe of the company's projects, it has been chosen for this research those projects that had considerable level of requests for design changes.

LITERATURE REVIEW

Custom in general definition is to meet or exceed customer expectations by enabling the injection of subjective and personal characteristics to a service or product (Santana, Oliveira and Meira, 2007). Within the Architecture-Engineering-Construction (AEC) industry, specifically at the construction companies, one of the customization tools is providing to the customer flexibility still in the design phase.

According to Farias (2013), the need for architectural flexibility has established itself as the society has become more tolerant to practices such as divorce, homosexual marriage, home offices, and late marriage. The customization is not a result from society, but from the individual human being, that has the tendency to want to differentiate itself from the other.

Oliveira (2012) defines flexibility as the free option to redo the internal arrangement of a fixed periphery. Before him, Brandão and Heineck (1998) listed different types of architectural flexibility, from which two stand out: 1) the offering of different plan options to be chosen from. This configures a customization, since the choice is very subjective and is made by the client himself, even though he was not the author of the plan options. 2) Providing the client with a basic plan along with the permission to change the internal spatial configuration (including the finishes), without infringing the construction rules.

Brandão and Heineck (1998) also say that the choice of the type of flexibility to be offered for housing customization is linked to the amount of private units of the project, and the gross area of each unit. Usually, projects with more units and smaller areas tend to offer Option 1, as those with larger areas and less units allow the application of Option 2.

Regardless of the customization pattern offered by a construction company, it will always be a marketing strategy, which can generate, in addition to customer satisfaction, an advertising channel and increasing of future sales by recommendation (Oliveira, 2007).

Regarding lean construction, the customization is related directly to the process of value generation. It considers the individual's perceptions referring to the satisfaction of its individual desires (Piller, 2003). With the same intensity that customization directs the sales, if it is not well planned, it can compromise quality, cost and deadline for delivering the product. The success of the process involves skilled labour, rigorous constructive control, and company standards and general rules.

RESEARCH METHOD

The research is quantitative, and it was developed with the tabulation of data generated after studies of different plan's layouts. All database was provided by the construction company. This study's universe corresponds to 50% of the customized units at a partial or full level (each tower) from two residential projects which must meet the criteria listed below:

Have similarity in the private area of the standard unit, thus the program of needs is similar;

Be located within the same region and have the same market focus (Upper Class and Upper-Middle Class), to ensure common interests;

Have been designed by different architects, so that different parties may be analysed concerning a similar program of needs;

Have been recently built, to ensure non-obsolete findings;

Have finished the customization process, to allow a complete analysis.

Two residential projects have met these requirements, and were named Building A and Building B here.

CASE STUDY DESCRIPTION

The buildings chosen for the case study have 8% difference between their private floor area, a similar number of units per floor and per tower, different architects and are recent enough to have their results applied to other projects. Table 1 brings both buildings features and characteristics.

Table 1. Building A and B features and characteristics

Criteria	Building A	Building B
Number of buildings	1	2
Apartments per building	42	44
Apartments' floor area	206m²	226m²
Architect	A	B
Focus	Upper Class	Upper Class
Month / Year of completion	May/2014	December/2014
Month / Year of conclusion of customizations	May/2013	December/2013
Percentage of simple customizations	5%	16%
Percentage of partial and full customization	50%	26%

In addition, Buildings A and B are located in adjacent neighborhoods, Meireles and Aldeota (respectively), both wealthy neighborhoods. The map on Figure 2 illustrates the location of both buildings, the distance between them is about 2km, and Table 2 shows the plans of the standard units of both buildings and the architectural program of each unit.

Figure 2. Map of Fortaleza (left) and Aerial photo of neighbourhoods Meireles and Aldeota (right).

Table 2. Standard units' plans

Building A	**Building B**
Plans	
	
L-shaped Living room with restroom	L-shaped Living room and restroom
3 suites (master suite with bathtub)	3 suites (master suite with closet and bathtub)
Home office and Linen Closet	Home office and Linen Closet
Gourmet balcony (barbecue area + countertop)	Gourmet balcony (barbecue area + countertop)
L-shaped Kitchen	Kitchen and pantry
Service area	Service area
Maid's room	Maid's room

THE CONSTRUCTION COMPANY

Founded in 1977 in Fortaleza, Brazil, the construction company of this case study focuses specifically on Upper Class and Upper-Middle Class. It has built more than 700.000m², distributed in several residential projects.

Since 2004, the company has been using many lean tools and practices such as *kanbans, andon, poka-yokes,* supermarket concepts in the warehouses, transparency tools, production in small batches, new solutions formatted asA3 tool, standardized work and many others.

THE COMPANY'S CUSTOMIZATION PROCESS

At the construction company there is a technical team exclusively dedicated to manage the customization process, which is responsible for registering the customer's decisions and analyse the customer's needs, as for finding project limitations and constructive constraints.

The process begins before the completion of the structure of the building's first floor, when a book that gathers information about the customization options and all technical information related to the apartment's project is sent to each customer. This book contains: a) a cover letter that limits the project's modifications and its finishes, and sets the deadlines for customers' choices to be made; b) the project set (plans and elevations) of the standard unit and its facilities systems (structural, electrical, hydraulic, and air conditioning); c) the memorial of material with the finishes previously specified and several illustrative images. At this stage, it is also placed on the construction site a showroom with all the finishing materials specified for the standard unit that helps to keep transparency of the process and to accelerate the customers' decision-making (Kemmer et al., 2010).

Through this material, the customer may choose between two different paths. The first is to select one of the layouts pre-configured by the construction company for the standard unit. The second path is the option to customize the interior layout according to his need (Figure 1).

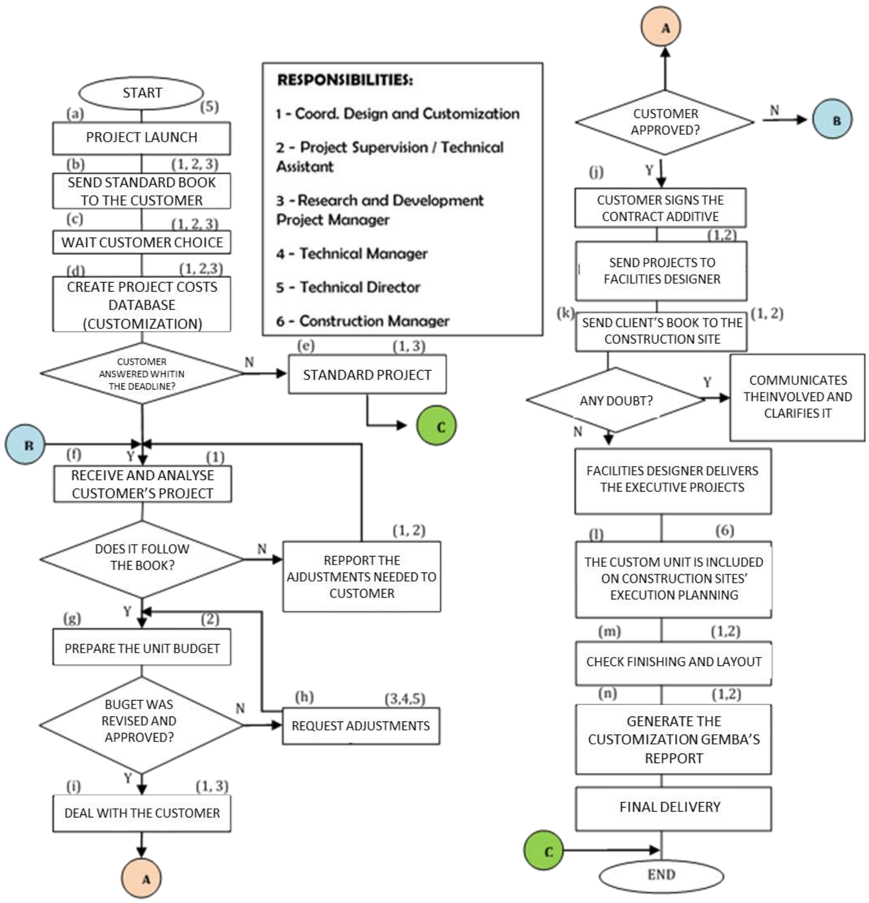

Figure 1. Company's Flowchart for Customer Customization.

By choosing the first path, the choice does not generate extra costs and the customer is entitled to choose one of the floor finish options within the default settings. By choosing the second path, the customer has to hire his own architect and other designers to prepare the set of projects containing the modifications requested. Once the customer has all projects (architectural, electrical, hydraulic, etc.) he must send it to the construction company within a deadline to be revised and executed, according to the standard previously determined.

The second option involves additional cost to the customer, the customization process is longer and more complex, as it can be seen in Figure 1. The costumer choices must be evaluated concerning technical constraints and they affect the construction directly.

The construction company ranks the free customization (with few constraints) into three types: simple, partial or total. The simple customization, the modification involves layout or finishing specifications without changing the installations systems. The partial customization reaches changes in the layout and materials' specifications, but still does not change its facilities. When the intervention reaches three attributes: layout, finishes and building installations, it is classified as total customization.

RESULTS

Given the tabulated data from the costumers' requests, this research aimed to identify the rooms that were added, deleted and maintained in the standard plan offered by the construction company for each project.

ACCEPTANCES

The rooms (or spatial arrangements) most frequently maintained by customers were: Maid's Room (100%), Closet (100%), Service Area (100%), Bathroom (100%), Gourmet Balcony (barbecue area) (95%), Kitchen (80%), Guest Bathroom (80%) and Linen Closet (80%).

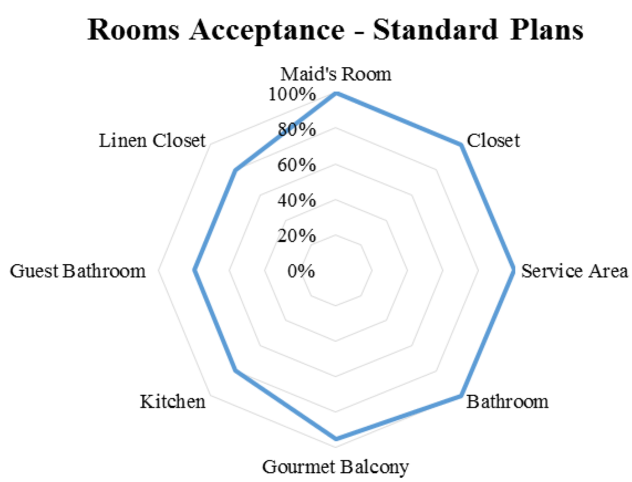

Figure 3. Percentage of acceptances of each room

The Maid's Room is a suite accessible for the housekeepers through the Service Area. Although currently the majority of Brazilian families hire a daily cleaner (employee who does not sleep in t), the result of this research indicated that the Upper Class still hires housekeepers and prefers to provide them with an individual room.

Regarding the Closet, the study showed that in all suites the residents usually have a space reserved for wardrobes. This space is usually near the bathroom door and is always wider in the Master Suite.

Within the analysed plans, 100% of the customers did not change the spatial arrangement of the Service Area, a room with functional linear sequence of laundry features (tank, scrubber and washing machine). The same occurred with the Bathroom, where the spatial usual sequence (countertop, toilet and shower) was maintained. The Master Suite's Bathroom and the Guest Bathroom were not accounted for this percentage.

The standard plan for both projects A and B brings the differentiate in a barbecue area in the balcony, the Gourmet Balcony. This spatial arrangement had 95% acceptance.

The spatial arrangement of the Kitchen was accepted by 80% of the customers. The standard plan offers a square-shaped kitchen, with stove, countertop and refrigerator arranged as a triangle, facilitating movement. Those who modified the kitchen did it tending to the functional arrangement where there is an island for the stove (20%).

The analysis of acceptance of the Guest Restroom brings the company the opportunity to verify its real need, as it was on the standard plan of Building A, but not in Building B. The results showed that it is a room required by Upper Class, as it was accepted in 80% of cases in Building A and was included in 70% of the projects in Building B.

Finally, the Linen Closet was maintained at 80% of the cases, but not necessarily as or the same size offered by the builder. Its location is in 100% of cases a dead space between two walls or pillars in the corridor of the apartment suites.

MODIFICATIONS, EXCLUSIONS AND ADDITIONS

Regarding the Living Room, the default L-shaped format was accepted by 70% of the clients. The other 30% included the expansion of this space, making it rectangular or square-shaped by removing one suite.

The research has shown that the amount of Suites (03) established by the standard plan was maintained at 45% of the cases, 20% of the layouts have reduced this number and 35% have increased it. This was the room that had more balanced results between maintained and modified (45% x 55%).

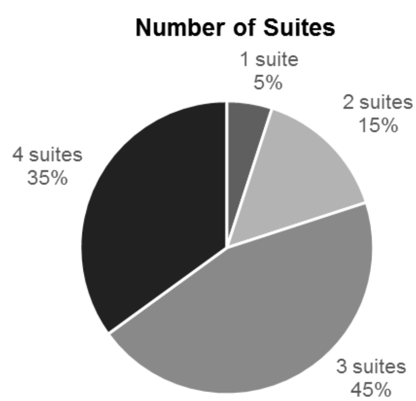

Figure 4. Number of Suites in the sample

Regarding the Pantry, the results were biased. Pantry is a room that guards groceries and / or other kitchen utensils. As the Building A's standard plan had no pantry, no changes on the kitchen's layout in this regard were observed. In the case of Building B, whose standard plant included the pantry, 70% of customers chose to keep it. This suggests that the pantry is necessary for the Upper Class customer, but when it is not offered in the standard plan, the resident solves his need with loose furniture or custom-made cabinets.

The survey found that both Home Office and Reversible Bathroom have lower acceptance, both were maintained only in 30% of the analyzed plans. Also in relation to exclusions, the bathtub was removed in 45% of the Master Suites analyzed. This last room had its other functions (toilet, shower and countertop with 02 sinks) maintained 100%.

Finally, it was observed that about 5% of costumers added an Intimate Living Room on the final layout of apartment.

CONCLUSIONS

The investigation made on layout's customizations in the projects of this construction company, showed that the standard plans offered by the builder are within the standards demanded by the market. However, being an architectural design research, up to the first drive usage year, on furniture phase, evaluates the satisfaction of the resident with the default layout.

In this research, the comparison of data has taken into account that room or spatial arrangements well accepted are those which had percentage of 80% or greater. Those that had percentage equal or lower than 40% were determined as not acceptable. Customizable attributes that had their maintenance in the range of 41% to 79% were considered as adaptable. Figure 5 summarizes the following results.

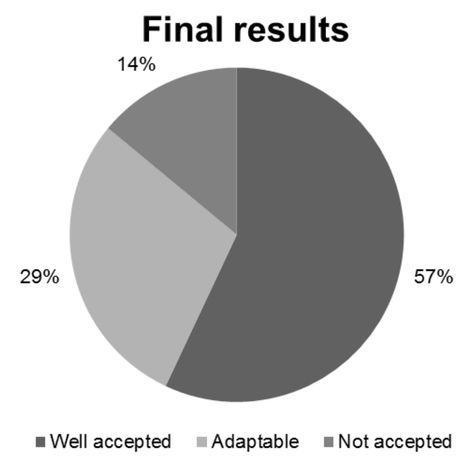

Figure 5. Summary of Results

Of the 14 attributes analysed, eight were classified as well accepted, four as adaptable and two were classified as not accepted. Almost 60% of the attributes were well accepted by customers and less than 15% were not well received. Thus, this article is an input to the developing the program of needs of plans for apartments of residential buildings that are similar to the studied profile, considering the following suggestions:

No longer include the Home Office and Reversible Bathrooms on standard layout;

Place the bathtub offered to master suite's bathroom as a customization option and not by default;

Allocate the Living Room, Suites and Pantry in a nuclear position on the plan, without any connection with structural functions, because they are rooms likely to be changed;

Keep the arrangement of Bathrooms with sink, toilet and shower;

Keep the items that had percentage of acceptance equal or greater than 80% (Service Area, Bathroom, Closet, Maid's Room, Gourmet Balcony, Square Kitchen, Restroom and Linen Closet).

Even though the construction company found assertiveness of the program of need, the customization should not be disqualified as a company's process. There are strong incidence of layout's changes by the residents, even with small flexibility in the standard program proposed. It was concluded that the customization is much more a personal desire of the owner, than a technical matter of adjusting the standard plan with outdated program of needs. Thus, although it is non-profitable and not technically necessary, customization is justified by the market character, sales and customer satisfaction.

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TRANSFORMATION-FLOW-VALUE VIEWS OF A COLORADO SCHOOL DISTRICT'S PROTOTYPING STRATEGIES

Bolivar Senior [1] and Bennett Nafe[2]

ABSTRACT

Key issues and strategies used by a school district in Colorado for the procurement and implementation of prototype designs for its buildings were examined in the exploratory study presented here. School construction prototyping involves the design and building of a project with the deliberate purpose of repeating it multiple times while allowing its constant improvement. The practice has been reported as having failed when attempted in several states, but it is currently a successful, standard practice of the researched school district. Issues were separated into those significant to the school district and those significant to the prototype designer. To clarify their taxonomy, issues were grouped into categories consequent to Koskela's process paradigm of Transformation, Flow and Value.

KEYWORDS

Standardization, customization, school prototypes, TFV paradigm.

BACKGROUND

School districts need to expand their capacity with limited or even shrinking funding. The need for more schools in the United States is underscored by documents such as the American Society of Civil Engineers' Infrastructure Report Card (2013), which indicates that almost one in ten public schools in the United States reports enrollment exceeding the building's permanent capacity by more than 25%. If this trend continues, significant new school construction will be required to meet space demands in an environment where construction needs are often limited by funding challenges. For example, in Colorado no state capital funding is allocated to school construction, placing the expansion cost burden on each school district (21st Century School Fund, 2014, Colorado Department of Education, 2014).

For tighter financial control, public school districts sometimes perform design and project management functions to satisfy space and building program needs, although such functions are outside their core competency of educating students. A challenge of such unique designs is that there is no capturing and integration of usable knowledge resulting from each one. This is especially true when each successive design proceeds from a different architect, who probably will be reluctant to share the design with the

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next project's architect. A building can be excellently designed and built, and yet its design could be ignored in the next project.

PROTOTYPING

Prototyping can offer an effective solution to learn from previous projects and reuse best design practices. The term prototype as used here refers to a project or major component of a project designed and built with the intent of repeating it multiple times (California State Allocation Board, 2000). Each instance of a prototype is considered a project. Since the design and construction of schools tend to have similar objectives and requirements, prototypes are attractive to school districts. Prototyping offers school districts the promise of improving efficiency, capitalizing on lessons learned and reducing costs in design and construction while avoiding duplication of mistakes (DeKalb County Board of Education, n.d.).

It has been claimed that prototyping has been used since at least the 1860s in Ireland (OECD Centre for Effective Learning Environments CELE, 2011). Non-scientific reports have been available from the 1960s and even earlier (Council of Educational Facility Planners International (CEFPI), (2009). A literature review for this study showed a scarcity of scholastic literature about the benefits and drawbacks of this approach, perhaps influenced by the fact that the term *prototype* as used here differs from its more common interpretation of a preliminary stage towards a final product. For example, Howell and Ballard discuss the nature of a construction project within the context of Lean Construction as being “analogous to the preparation of a prototype” (Howell, G. and Ballard, G., 1997), implying the most common use of the term *prototype*. The term is common in the technology industry, although also used as a near-synonym for a preliminary stage in software or hardware development. Another example can be found in Sacks, Ronen, Belaciano, Gurevich and Pikas (2013), which describes an early tool of a new information system developed by the authors as “an early prototype of a novel workflow management information system for construction”.

CURRENT CONDITIONS

USE OF PROTOTYPING

Several countries report a successful use of prototyping and using it as a standard practice for school construction. The OECD Centre for Effective Learning Environments (CELE), (2011) discusses the experiences of several countries with prototyping, such as the province of Alberta, Canada, which claims to have saved CAD 97 million between 2007 and 2011 along with two years of saved construction time. The report also mentions that between 1959 and 1970 Mexico built and furnished 54,000 classrooms and has used the experience for its current standard designs. Comparable levels of success for school prototypes are included in the OECD report for Australia, Brazil, Portugal and other countries.

Reports about the use of prototyping for school building construction have been commissioned and published in the U.S. mainly by state legislatures, school districts and professional associations. While some districts show enthusiasm for this approach (e.g., Horry County Public Schools, n.d.), many other reports have found significant drawbacks on the use of prototypes. One of the most comprehensive compilations of such shortcomings is the State of Arkansas Public Relations Committee's report on prototypical building designs (2004). It asserts that prototyping would need "a large staff" of architects and engineers to update the plans, it would eliminate competition, require a large number of designs, adjusted to code that "change yearly", consider diverse seismic conditions, an architect would be still needed for each project, and the "liability question all but eliminates any money saving of architect's fees". Its accuracy is negatively impacted by stating that only four states of 41 surveyed by a previous study reported ever using prototypes. Colorado and California were among the states reported as not using this design approach, despite evidence of its use in both states, as discussed in the next paragraphs. Moreover, the American Institute of Architects, reports that 25 states have used prototyping (American Institute of Architects, 2005).

Other studies contain negative considerations about prototyping (e.g., CEFPI, 2009, Alaska Department of Education & Early Development, 2015, DeKalb County Board of Education, n.d.), although less radically than the Arkansas report. Criticism about prototyping includes the lack of community involvement in the design process of a given school (Department of Education, Commonwealth of Virginia, 2002), the costs associated with customizing a design to a particular site conditions, the design differences for elementary vs. middle and high school programs, rural vs. urban districts and small vs. large districts (Alaska, 2015). It has been reported that "Prototype school designs save time, money; critics say schools lack identity." (Gray, 2014).

A promising approach has been called "kit of parts" (CEFPI, 2009) consisting of the partial application of prototyping by zones. A clearinghouse of best practices maintained by the School Planning Section of North Carolina Department of Public Instruction (n.d.) provides a useful source for designers.

The California State Allocation Board (CSAB) Public School Cost Reduction Guidelines (2000) are an important and deliberate effort to comprehensively address school prototyping issues. The guidelines were developed by construction expert workshops as a way to reduce construction process costs and to determine best practices and critical success factors for new public school building construction. This study utilizes with only minor modifications the division of prototyping issues contained in these guidelines.

DOUGLAS COUNTY SCHOOL DISTRICT

This study centers on the prototyping practices of the State of Colorado's Douglas County School District (DCSD), which serves suburban areas and towns immediately south of Denver. It has experienced large enrollment growth and capital expansion in recent years, resulting in the construction of a substantial number of new school buildings. Currently there are approximately 67,000 students currently enrolled in the district, ranking it as the third largest in Colorado and 59th largest in the United States. The District operates 48 elementary schools, nine middle schools, and nine high schools with a total budget of nearly $700M (2013-2014 school year) and 7,000 employees. In addition, enrollment is expected to double over the next twenty years (Douglas County School District, 2016). DCSD has used prototypes for years for new school building construction of more than 50 schools. The use of prototyping is considered to have minimized construction costs, design fees, and project schedule duration (Colorado Governor's Energy Office, 2013).

DCSD has achieved considerable success with the use of prototypes for its new school building projects. This study's interviewee reports that prototyping has saved DCSD about 25% in design fees and 17%-18% in construction bids. Furthermore, the use of prototypes has saved up to six months in total development and construction time when used in repeated designs. This study did not attempt to compare these notable results with performance at other school districts.

Some key DCSD management personnel involved in the district's use of prototypes are close to retirement. The experience of these individuals are at risk of being lost when they retire. An important motivator of the present study was the preservation of their knowledge to the greatest possible extent.

OBJECTIVES

This paper presents the results of a pilot study which investigated key issues faced by DCSD concerning the design, procurement and management of its school building prototypes. A primary objective of the study was to serve as a reference for future administrators of this school district and a point of comparison for administrators elsewhere. A secondary objective of this study was to preserve the knowledge accumulated by some key DCSD management personnel involved in the district's use of prototypes who are close to retirement. The study was intended to serve as a compendium of key DCSD's practices, but did not attempt to compare them to other school districts' policies or whether school building prototyping has merits to be generally recommended.

THEORETICAL FRAMEWORK AND METHODS

The method for this case study involved the collection and analysis of public information and in-depth interviewing of the DCSD's administrator for school construction. It followed the standard in-depth interview methodology of thematizing, designing, interviewing, transcribing, analyzing, verifying and reporting. In-depth interview research cannot be subject to the generalization standards of quantitative research. Its objectives are built around program refinement, issue identification, and strategic planning (Guion, Diehl, and McDonald, 2011). These limitations restrict the use of in-depth interviewing to exploratory studies such as the present one.

The issues addressed here follow the breakdown of topics in the CSAB's guidelines (CSAB, 2000), and were grouped into categories consequent to the process criteria of the Transformation-Flow-Value (TFV) paradigm developed by Koskela (2000). Although primarily focused on the understanding of production processes, the TFV paradigm has a broad philosophical scope, allowing its use for the taxonomy of issues addressed by this study.

Koskela has used the term "world views" to refer to the division into Transformation, Flow and Value, since they reveal comprehensive assumptions about reality and management of reality. The Transformation view focuses on the realization of value adding activities. It is the *What* of the investigated reality; the Flow view is focused on reducing the share of non-value adding activities. It is the *How* part of reality; in the Value view, the focus is the improvement of customer value. It is the *Why* view. The left side of Figure 1 is a compact summary of the TFV paradigm shown on Table 4 of Koskela (2000), providing more detail about these definitions, used as guidelines for the grouping of the CSAB's issues discussed here.

An analysis of collected information, particularly the interview transcript from the DCSD's main construction administrator, led to the grouping of District and Designer issues under the Transformation, Flow and Value views. This grouping was ultimately subjective, although a thematic analysis of the interview and published data provided consistency to the assignments. The opinion of the main construction administrator was also instrumental to the details in the list. The right side of Figure 1 contains the issues addressed here and their grouping under Transformation, Flow and Value. The use of the TFV paradigm as the basis for the static taxonomy of this study provided insight into the underlying dynamics of DCSD's management processes concerning prototyping.

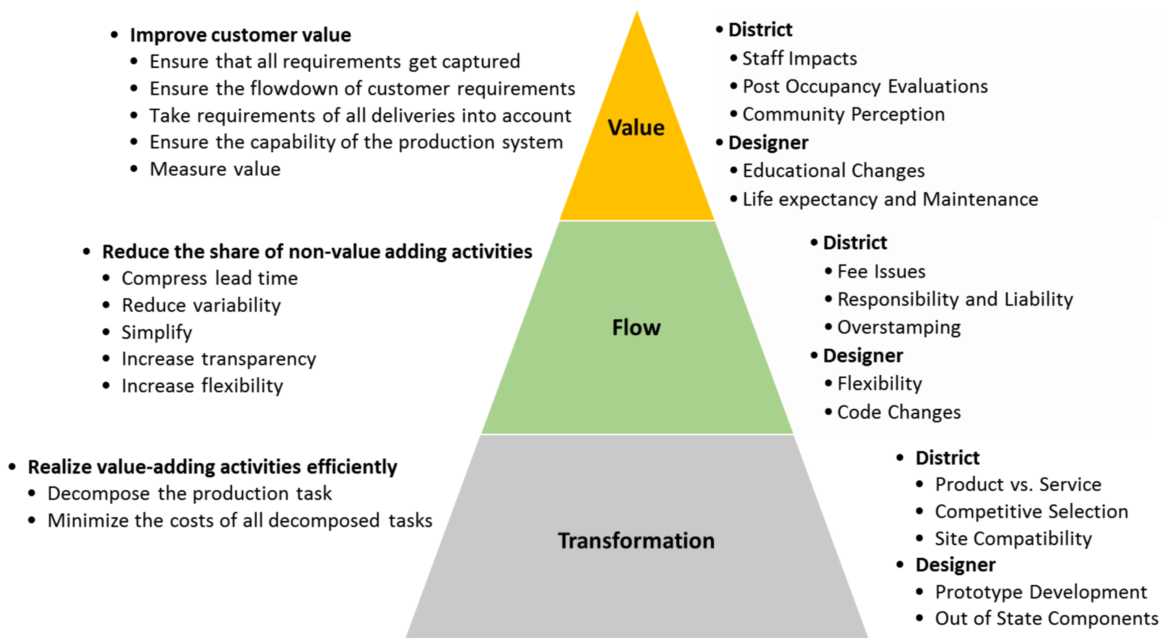

Figure 1: TVF Principles and Addressed Issues

FINDINGS

The following findings summarize the issues addressed by this study. As previously discussed, these findings resulted from public records and in-depth interview and consultation with the district's main construction administrator.

PRACTICES UNDER THE TRANSFORMATION VIEW

Issues under the Transformation view concern tasks for the input and output of the prototyping process, paralleling Koskela's partial description of Transformation as acquiring the inputs to these tasks with minimal costs and carrying on the tasks as efficiently as possible." (Koskela. 2000).

District Considerations

- **Product vs. Service.** DCSD begins prototype design projects by negotiating terms for subsequent projects that make use of the same design. Clarification of this diminishing role of the designer early in the process works to mitigate concerns of declining professional services with prototype use. Setting the expectation for a limited prototype life span addresses this concern.
- **Competitive Selection.** DCSD manages competitive selection by hosting design competitions complete with stipends to encourage participation and fair and open competition within the architecture community. The selected designers can, eventually improve their own existing prototypes as their repeated use serves to detect flaws in design or construction.
- **Site Compatibility**. A major lesson learned from the regular use of prototypes has been the development of features relatively easy to adopt by various site situations, especially in their ability to adjust foundations to differing soil conditions.

Designer Considerations

- **Prototype Development**. DCSD requests designs based on changes in funding, community preference, and educational program needs. Although the district has found that the initial development of prototypes can be more time intensive than a unique design, a prototype development is most successful when all factors such as program-driven space needs, community preferences and input, district standards, and funding implications are considered.
- **Out of State Components.** Impacts of factory-built components have been limited in DCSD projects by the district's design and materials selection policies. Products from out of state or non-compliant with code requirements without modification are avoided as much as possible.

PRACTICES UNDER THE FLOW VIEW

The issues grouped here under the Flow view address the “minimizing [of] the share of non-transformation stages of the production flow, especially by reducing variability.” (Koskela, 2000). The issues below, accordingly, concern the stabilization of the prototyping process, especially from the district’s viewpoint.

District Considerations

- **Fee Issues.** DCSD negotiates an initial fee for each prototype design with its designer and contracts each prototype separately. Fees for prototypes can be lower per project when compared to unique designs and that fee issues can be resolved through negotiated agreements for each project independent of other concerns. This approach leads to a lower average designer fee per project.
- **Responsibility and Liability**. The ownership of prototype designs may come with liability of design flaws and other complex legal concerns. DCSD manages these issues by stating intent to reuse and improve prototypes during the design phase, taking ownership of the designs, keeping the original consultants involved, and selecting one architect of record. A particular challenge faced by other district is the design’s **overstamping.** States such as California require any design to be stamped by a single architect regardless of the number of

contributing designers. Colorado does not require single-stamping, thus avoiding this substantial ownership dilemma.

Designer Considerations

- **Flexibility**. DCSD requires the use of prototype designs with the flexibility to adapt to new educational requirements. Designers (and most educators) cannot project in detail new educational approaches or mandates, and therefore, this requirement results in designs with scalable features varying from relatively small changes, such as room use and layout, to large ones such as wing expansion and knockout walls. Flexibility is enhanced by DCSD's strategy of "kits of parts", close to the recommendations of the Council of Educational Facility Planners International (2009) previously discussed. The initial design process flow is larger than if a single design is prescribed, but the design flow is stabilized by the larger number of valid alternatives for subsequent repetitions.
- **Code Changes.** Changes in code requirements that are adopted between the creation of a prototype design and its use may require updates and changes in design and construction that may reduce the prototype's value. DCSD mitigates the impact of future code changes by designing the initial prototype to exceed safety and efficiency standards of current code and actively participating in design updates. As in the case of flexibility issues, the aim of these initial precautions is to avoid instability in the future.

PRACTICES UNDER THE VALUE VIEW

The Value view "views production as a means for the fulfillment of customer needs. Production management equates to translating these needs accurately into a design solution, and then producing products that conform to the specified design." (Koskela, 2000). While the internal customers of a school district are its students and indirectly the students' families, its ultimate, external customers are the taxpayers funding the district's operations (in the case of the U.S., parents of the district's student population are also important external customers, directly paying for about a third of the school's expenses through their school mill levy). Issues under this view concern the value of a prototype to their customers. In the case of the DCSD, the key practices presented below emphasize the feedback to its staff and the community.

District Considerations

- **Staff Impacts.** As a strategy to demonstrate the value of prototyping to its staff and to reduce the impact of required expertise outside the district's staff experience, DCSD has chosen to use the Clark County School District of Nevada (Clark County School District, 2012) as a resource and model. The Nevada District had previously used prototype schools to respond to rapid population growth. Learning from a peer district minimizes initial negative impacts of prototyping in terms of learning curve and lessons learned from the district's viewpoint.
- **Post Occupancy Evaluations (POEs)**. The objective of POEs is to improve future designs through feedback from occupants, owners, and other stakeholders. DCSD conducts POEs to analyze successes and areas for improvements. For example, bid and construction process for one project may

need to begin before the POE from the most recently completed prototype is available, requiring lessons learned from a previous iteration to be used as the primary source of feedback.
- **Community Perception.** DCSD is aware of the importance of maintaining the community aware of its plans, and explains in advance the nature of prototypes. This strategy provides value in both directions: the community can provide input to the process, and DCSD can explain its plans.

Designer Considerations
- **Educational Changes.** The flexible spaces and adaptable features to address future educational changes are critical success factors for district consideration with prototypes. Designers must show vision and creativity for this changing factor, which they cannot know in any detail.
- **Life expectancy and Maintenance**. DCSD has found that prototype design enhances value engineering through repetition and allows experience to guide design and purchasing decisions to increase both service life and efficiency of the buildings.

DISCUSSION

DCSD emphasizes clarity on the roles of the many stakeholders in the construction of a school building prototype, and particularly on the definition of the district's relation with the prototype designer. From the designer's viewpoint, the challenges and strategies are different but interlaced with the district's.

- **Transformation view.** The *What* of the prototyping process is centered on the definition and selection of the designer and its services for DCSD, and in the tangible result of the design for the designer. This district is large and in need for solutions to its rapid growth, and its constituency is relatively uniform in key socioeconomic aspects (Douglas County School District, 2016). Size, growth and student body uniformity have been singled out by at least one report (Alaska, 2015) as ideal for the implementation of school prototypes.
- **Flow view.** The *How* is centered on the stabilization of the design and procurement process flows. For the most part, this is as a set of issues and strategies about the short and long-term cost and liability of the design effort. DCSD’s approach toward these issues is the selection of a single designer for each prototype. From the designer's viewpoint, the challenges are more standard in the sense of involving creativity and vision for designs that can be tailored to a particular case and be updated to future building code requirements.
- **Value view.** The *Why*, from DCSD's perspective, involves the value to its customers deriving from the use of prototypes. The deliberate use of peer districts' experiences has simplified the learning and management of prototypes. DCSD follows a proactive policy of information and feedback with the district's stakeholders through POEs and community education about upcoming projects, which has clarified the value of prototyping to its customers.

CONCLUSIONS

This study provides a summary of successful practices for the implementation of prototyping by the DCSD as evaluated by its main construction administrator and supported by published information. The issues have been broken down using the guidelines of the California State Allocation Board (2000), and grouped under Koskela's (2000) TFV process paradigm. The study provides descriptive as opposed to prescriptive information, as its main purpose was to offer a rational taxonomy of the successful practices followed by DCSD.

The successful practices followed by DCSD contrasts with the reported failures of some other school districts attempting to implement a policy of school construction prototyping. The district has many of the positive factors mentioned by other reports addressing the use of prototyping, such as being a large, growing district with personnel willing to learn the virtues and limitations of this designing approach.

Given the reduced scale of this study, this paper does not attempt to compare DCSD's performance with that of other districts. While this study's results show the promise of obtaining positive results when a consistent approach to procure and manage school prototype designs is used, other districts may have different circumstances warranting different solutions. Further research should consider the value and limits of school prototypes as a response to the current circumstances of K-12 education.

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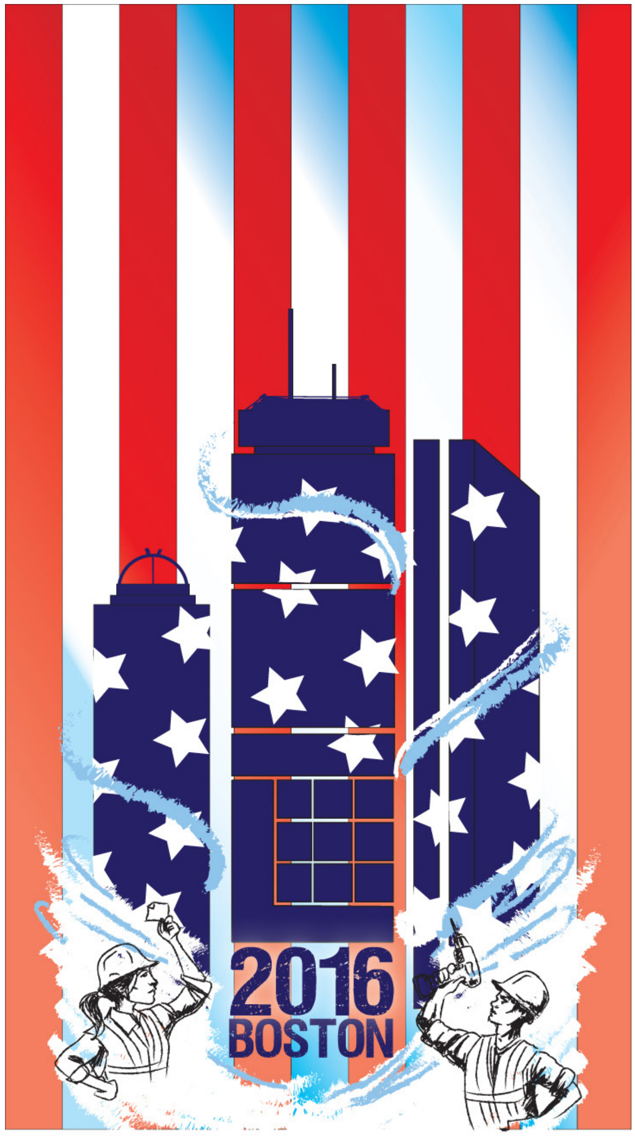

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