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USE OF VIRTUAL DESIGN AND CONSTRUCTION, AND ITS INEFFICIENCIES, FROM A LEAN THINKING PERSPECTIVE

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ABSTRACT

In recent years, the Architecture, Engineering and Construction (AEC) industry has broadly expanded the use of Virtual Design and Construction (VDC), particularly Building Information Modeling (BIM). However, this use is not always well planned and defined by the companies, which introduces inefficiencies in their VDC use.

This research explores the literature to identify examples of waste in VDC from a Lean Construction perspective, and proposes VDC practices and Lean methods to reduce this waste.

The exploratory research found examples of 8 waste types in the use of VDC: Non-value added processing, Motion (excess), Inventory (excess), Waiting Overproduction, Employee knowledge (unused), Transportation/Navigation, and Defects.

KEYWORDS

VDC, BIM, Lean, Waste

INTRODUCTION

A significant body of literature exists to describe lean production methods as well as lean construction theory and applications. Great advances have forced and enabled the construction industry, considered one of the most resistant to change, to use new methods that allow it to survive. Virtual Design and Construction VDC and Lean Construction allow the construction industry to face different challenges (Khanzode, et al., 2006; Khanzode, et al., 2007; Khanzode, et al., 2008). Multiple investigations

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converge in the potential that is achieved by implementing both initiatives together (Enache-Pommer, et al., 2010; Fischer, et al., 2008; Gerber, et al., 2010; Messner, et al., 2010; Sacks, et al., 2010; Sands and Abdelhamid, 2012; Tommelein and Gholami, 2012). This research aims to extend Lean Construction as an initiative that can "branch" throughout all processes of VDC, including information flow. As a starting point, we define the three concepts for the specific purposes of the study:

VIRTUAL DESIGN AND CONSTRUCTION

Kunz and Fischer (2011) defined VDC models as: *"The use of integrated multi-disciplinary performance models of design-construction projects to support explicit and public business objectives."* The Center for Integrated Facility Engineering (CIFE) indicates that a project is a set of information flows that can be modeled and represented in a computer using symbolic representations of Products, Organizations, and Processes (P-O-P) (Khanzode, et al., 2006). The purpose of VDC is building models of P-O-P early before a large commitment of time or money is made to a project (Khanzode, et al., 2006).

Many tools have emerged from VDC methodology, such as Building Information Modeling (BIM). Researchers have viewed and defined BIM from different perspectives. Eastman, et al. (2011) defined BIM as a modeling technology and associated set of processes to produce, communicate and analyze building models. McGraw-Hill (2009) emphasized that BIM is the process of creating and using digital models for design. That study also noted that BIM serves as a shared knowledge resource for information about a facility and a reliable basis for decision making (National BIM Standard, 2008). Kjartansdóttir (2011) viewed BIM as a process of creating and sharing data and information in a digital format.

Although the terms VDC and BIM are used interchangeably by some, BIM represents the form/scope of the product, which is a crucial but small portion of the VDC framework (Kunz and Fischer, 2011). When we reference VDC, we refer to the entire framework method (P-O-P), which has BIM as a part of the product definition. BIM relates to other methods and tools such as production models, critical path method (CPM) schedules, organizational models and 4D models. 4D refers to the four dimensions of X, Y, Z and time, i.e. 4D is 3D BIM+ schedule (time)

In this analysis, we focus on VDC as a process. A process is a structured, measured set of activities designed to produce a specified output. It implies a strong emphasis on *how* work is done within an organization, in contrast to a pure product focus emphasis on *what* (Davenport, 1993). VDC includes models, but it also includes properties of model elements, or data, as well as processes to plan, create, check and act using models.

LEAN PHILOSOPHY

Lean is a management philosophy that provides methods to identify waste and uses a number of tools and principles to remove them. Instances of waste can be found at any stage of the project, from the beginning to the information flow and the construction phase. The more waste is eliminated, the better the results (Plenert, et al., 2012). Koskela (1992) adapted the concept of Lean Production to the construction industry by formulating a new production philosophy called "Lean Construction."

Although, there are studies that point out how the impacts of VDC can be directly associated with Lean Principles (product view), the study outlined in this paper suggests that Lean Construction can help to reduce waste within the VDC in the phase of information flow (process view).

LEAN IT

Manufacturing has been a reference point and a source of innovations in construction for many decades (Koskela, 1992). In the early twenty-first century, a new approach called Lean Information Technology (IT) emerged, which aims to identify and eliminate waste within IT development processes, focusing primarily on information flow. Bell and Orzen (2010) defined Lean IT as: *"the use of Lean principles, systems and tools, to integrate, align, and synchronize the IT organization with the business to provide quality information and effective information systems, enabling and sustaining the continuous improvement and innovation processes."* Lean IT aims to improve the performance of IT processes and services. Bell and Orzen (2010) noted that the lack of Lean commitment within organizations is one of the root problems that cause failure in the implementation of IT.

LEAN OFFICE

The ultimate goal of Lean is to create a culture of continuous improvement every day, on every product or service, by everyone. Lean Office is the application of Lean Manufacturing to the administrative processes (Pestana, 2011; Ryan, 2010). A 5S is a process to ensure work areas are systematically kept clean and organized, ensuring employee safety and providing the foundation on which to build a Lean Office System (Kremer and Tapping, 2005).

METHODOLOGY

The research method for our study was an analysis that describes actual applications of VDC and Lean Construction as described in the literature. This analysis refers to methods that focus on contrasting and combining results from different studies, in the hope of identifying patterns among study results, sources of disagreement among those results, or other interesting relationships that may come to light in the context of multiple studies (Rothman, et al., 2008). Our analyses depend on the accuracy and thoroughness of the published studies we reviewed. For this paper, we attempted to gather all existing studies that discussed occurrence of waste within actual implementation of VDC practices. The analytic method adopted consists of searching, coding and providing a descriptive analysis to synthesize the findings of VDC studies that have previously analyzed. After the extensive search, we analyzed references to waste and classified these occurrences into eight types of waste reported in the VDC literature (for reasons of space, we put only seven examples of waste found in the literature).

SEARCH PROCEDURES

An extensive search of construction and related literature was initiated. Each study was subjected to inclusion rules for aggregation. A study was included if:

- The studies reported the current VDC practices (focus on the information flow).
- The studies were considered of highly quality. Two major online databases (ASCE and Science Direct) were reviewed from 2001 to 2013.

The types of waste (column 1 in Table 1) were based on the waste found in the Lean IT literature. Some of the examples are mentioned in VDC literature, while some others are not yet mentioned (Table 1). We found forty-three references to waste in the implementation of VDC in the twenty-nine papers we analyzed. Based on Plenert, et al., (2012) Table 1 defined the eight types of waste in VDC processes found.

Figure 1 shows the frequency of references to waste in cases documented in the literature. The Pareto chart shows that only five types of waste represent 80% of the references, which suggests that if teams focus on elimination of them (non-value added processing, motion (excess), inventory (excess), waiting and overproduction), they can improve VDC practices dramatically.

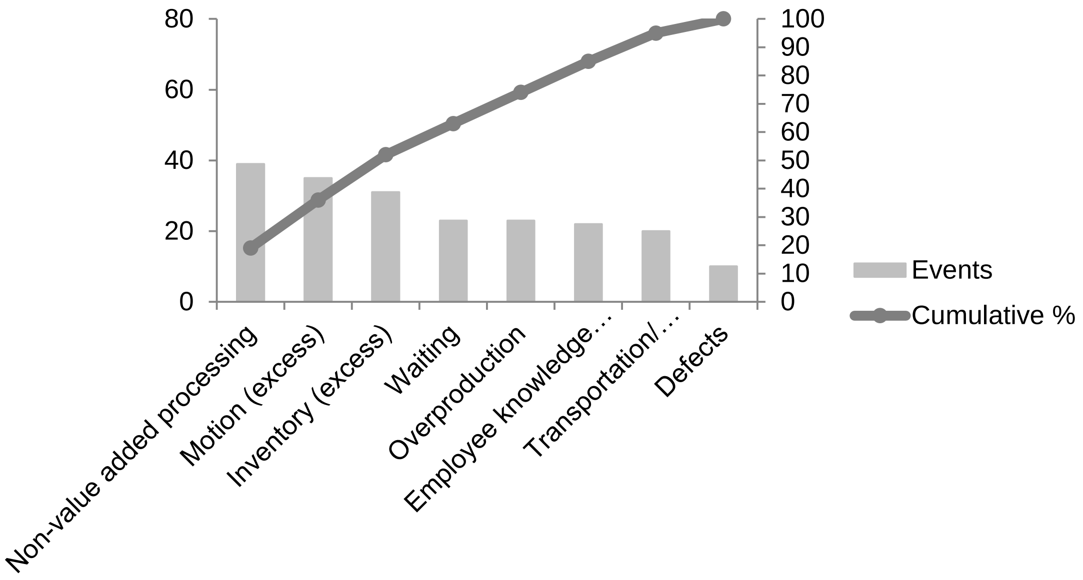

Figure 1: Number of references to waste in the literature

Table 1: Eight types of waste in VDC practices and examples found in the literature. Adapted from: Waterhouse (2008) and Plenert, et al. (2012)

Types of waste	**Definition**	**Some Examples:**	**Business outcome**
Defects	Non-conformity of a process or process step outcome.	Inadequate documentation. Defects. Rework. Poor/ incomplete documentation. Software bugs.	Poor customer service, increased costs.
Overproduction	Delivering more than what is necessary to fulfill customer requirements.	Duplicate test cases Extra features. Unused features.	Increased costs and overheads: energy, data, and maintenance.
Waiting	Idle time until arrival of a work item from a downstream process task. Delays occur between VDC activities.	Slow VDC application response times. Long synchronization cycles between application platforms. Searching for information. Delays from excessive review and approval steps	Lost revenue, poor customer service, lower productivity, and increased total cycle time.
Non-value added processing	Providing more options, functionality, and features than needed/requested by the customer.	Producing and distributing reports that are not used. Unused functionality in software. Ineffective and repetitive meetings (e.g. Big-room).	Miscommunication.
Transportation/ Navigation	Physically moving work items between subsequent tasks in a process.	Poor user interfaces. Navigate through a series of applications in order to accomplish a repetitive task.	Higher capital and operational expenses.
Inventory (excess)	Keeping available more services or material than needed or backlogs that occur in the execution of a process.	Documentation reviews. Support team queues. Multiple repositories to handle risks and control.	Increased capital expense, lost productivity.
Motion (excess)	Physical movement in the course of performing a particular task	Fire fighting repeat problems within the VDC infrastructure. People going to a meeting, not prepared (e.g. Big-room). Inefficient “movement” of data within the system.	Lost productivity.
Employee knowledge (unused)	Unconsidered knowledge and experience of people involved in the process	Failing to capture ideas. Knowledge and experience retention issues. Excessively detailed standards – no flexibility. Not investing in VDC education and training.	Talent leakage, low job satisfaction, increased support and maintenance costs.

KEYS TO A SUCCESSFUL VDC WASTE REDUCTION PROCESS

Developing an effective waste reduction process for VDC implementation is an important task before thinking about the final project results. An example is a study conducted by Freire and Alarcón (2002); based on principles of Lean production, they proposed an improvement methodology for the design process in construction projects. The authors concluded that the methodology resulted in improvements, not only for the efficiency and effectiveness of the internal engineering products, but also for the whole project. Table 2 summarizes our recommendations, based on Lean office, to reduce these kinds of waste within the VDC information flow (Kremer and Tapping, 2005; Pestana, 2011; Ryan, 2010).

Table 2: How to reduce the waste within the VDC information flow from a Lean perspective

Types of waste found in the literature	How Lean can help to reduce this waste
Non-value added processing	Use an A3 reports. Use set based design. Delay decisions until last responsible moment.
Motion (excess)	Define the scope of the models. Develop an agile process to anticipate to customer needs (customers can be internal, external, direct or indirect).
Inventory (excess)	Protocols for sharing models. BIM libraries. Meeting and quality protocols.
Waiting Overproduction	Development of a communication plan. Value-Stream Mapping (VSM).
Employee knowledge (unused)	Promote normalized coaching. Capture, communicate and apply experience-generated learning.
Transportation/Navigation	Develop 5S plans.
Defects	Use simple, grass-roots level suggestions to eliminate waste.

SUMMARY AND CONCLUSIONS

This exploratory research (based on literature) demonstrates there is a lot of waste in current VDC practices. Lean Thinking, as a framework, can help AEC companies reduce waste and create a more efficient VDC processes. Multiple investigations concur on the potential that is achieved by implementing both initiatives. Furthermore, VDC provides the means and methods to implement Lean Principles and incorporate management principles that help eliminate waste, reduce costs, improve productivity, and create positive results for projects. Eighty percent of the literature references represent five types of waste, suggesting that if teams focus on eliminating those five types, they can improve VDC practices dramatically. The five types of waste are:

- Non-value added processing,
- Motion (excess),
- Inventory (excess),

- Waiting and
- Overproduction

We proposed some Lean Practices that could help the AEC industry to reduce waste in its VDC implementation. For example, using set-based design can help to reduce the non-value-added processing. Value-Stream Mapping (VSM), a diagram of every step involved in the material and information flows needed to bring a product from order to delivery, can be an option to reduce overproduction. Moreover, gathering people and/or processes in order to improve workflow e.g. protocols for sharing models, BIM libraries, meeting protocols, and quality protocols can help to reduced the inventory (excess).

As we said before, this literature survey suggests that VDC practice, although clearly broadly used, seem informal in practice and clearly frequently include waste as viewed from Lean perspective. This conclusion suggests that VDC practitioners may benefit from careful attention to their VDC management processes to reduce waste, such as those that are implicit in the implementation of VDC methodology. Only when Lean principles, systems and tools are applied through every single phase of VDC practice the AEC industry can take better advantage of both methodologies.

Future research should be continued with a deeper study of information management within VDC using the lean thinking approach.

- Make a field study using Value Stream Mapping (VSM) and 5S to assess waste in construction projects for the use of VDC.
- Understanding the waste found in the literature.
- Develop models to measure the impact of strategies in the VDC implementation.

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APPENDIX

Table 3: Number of references to waste within projects in the literature that reported VDC use

	EVIDENCE FROM ACTUAL PRACTICE AND/OR RESEARCH	Defects	Overproduction	Waiting	Non-value added processing	Transportation	Inventory (excess)	Motion (excess)	Employee Knowledge (unused)
1	Time spent on re-entering the data from BIM to another application is considered the main driver of additional costs. Time spent using duplicate software is ranked second in the drivers of non-interoperability. Other drivers are: time lost to document version checking, increased time processing requests for information, and money for data translators (McGraw-Hill, 2007)	•	•		•		•	•	
2	Since the lack of clarity in qualitative goals for BIM use can result in wasted effort, like over-detailing a model or not fully capturing data in formats useful to existing facility management systems (Sciences, 2012).	•	•		•		•	•	
3	The project team must employ the same reference point (0,0,0) so that the models integrate appropriately in all three dimensions. This is extremely important for 3D coordination otherwise the team will spend a lot of time trying to combine the models together for conflict detection purposes (Staub-French and Khanzode, 2007).		•	•	•	•	•	•	•
4	BIM project teams will need strong individuals to manage model input and changes. Controlling access to all the "pieces and parts" will be a daunting task. Updating and tracking model changes requires a sound document control protocol to assure all team players are using the most current version of the model (Prather, 2013).			•	•	•		•	
5	Everyone has acknowledged that digital copies are better [than paper]. My question is, how will that work going forward when you have a huge inventory of digitized information? As a result, each project has a large amount of information which makes searching for specific items more difficult. We found no consistent procedure for naming or storing information from project to project (Dossick, et al., 2012).		•	•	•	•	•	•	
6	"Electronic files could be harder to find than paper files," and reached into his desk drawer for the hard copy. Standards go beyond naming conventions and define also the types of data to be stored" (Dossick, et al., 2012).		•	•	•	•	•	•	