ANALYSIS OF THE IMPLEMENTATION OF VDC FROM A LEAN PERSPECTIVE: LITERATURE REVIEW

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ABSTRACT

VDC (Virtual Design and Construction) models are seen as an important tool in the AEC (Architecture, Engineering and Construction) industry. The VDC methods allow stakeholders to integrate and transmit information throughout the project life cycle, in order to meet customer requirements. Furthermore, VDC is seen as a new approach that will help the AEC industry in achieving Lean principles by eliminating waste, reducing costs, improving productivity and creating positive results within the projects. The Lean philosophy can be used as a conceptual framework for the implementation of VDC, because the impacts of VDC can be associated directly with Lean Principles. Despite the importance of VDC, its implementation is based on anecdotes and beliefs from past projects making it difficult for the industry professionals to formalize implementation lines (factors and metrics) and apply them throughout the project. This research aims to analyze the current implementation of VDC from a Lean perspective. Our analysis includes studies – in the form of surveys, interviews, case studies, literature reviews and implementation guides– that have been conducted in order to assess the implementation and impact of VDC in the AEC industry. The results highlight the importance of the VDC implementation (benefits and obstacles), the lack of tools to identify strategies for successful implementation and the connection between VDC and the lean philosophy.

KEYWORDS

Collaboration/collaborative, lean construction, BIM, VDC, integration, production, integration, implementation strategies.

INTRODUCTION

The major challenges facing the Architecture, Engineering and Construction (AEC) have brought a new way of working, forcing companies to use new methodologies such the model called virtual design and construction (VDC) (Fischer and Kunz 2004). The use of VDC has expanded considerably in recent years (Fischer and Kunz 2004, Gao 2011, Gao and Fischer 2008, Kong 2010, Kunz and Fischer 2011, O'Ryan

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2011). This research presents a literature review on the current implementation of VDC from a Lean perspective.

Section 1 presents the study's research method. 30 studies were analyzed and broken down, in order to show the main topics presented in the literature. Section 2 reports on the findings from the review of the literature. Section 3 shows 20 of the 128 (Mandujano et al. 2013) new interactions added to the matrix proposed by Sacks et al. (2010a). These new interactions complete the matrix proposed by Sacks et al. (2010a) but also helps analyze the current VDC implementation from a Lean perspective and can help identify new VDC and Lean adoption strategies. Section 4 identifies the key gaps in the literature. Finally, in section 5 the conclusions and the implications for further research are outlined. As a starting point we define two key concepts in the research:

VIRTUAL DESIGN AND CONSTRUCTION (VDC)

VDC models are defined by Kunz and Fischer (2011) as: "The use of integrated multi-disciplinary performance models of design-construction projects to support explicit and public business objectives".

LEAN PHILOSOPHY

Lean Production born as a concept born from the study of the Toyota Production System (TPS). The aim of TPS is producing value, as defined by the customer, while maintaining optimal (Lichtig 2006). Koskela (1992), adapted the concept of Lean Production to the construction industry by formulating a new production philosophy called: Lean Construction. Lean Construction refers to the application and adaptation of the principles of the Toyota Production System (Sacks et al. 2010a). The Lean philosophy can be used as a conceptual framework for the implementation of VDC, because the impacts of VDC can be associated directly with Lean Principles (Sacks et al. 2010a).

METHODOLOGY

Relevant studies published between 2005 and 2013 were identified through the ASCE library, ScienceDirect, Engineering Village, Web of Knowledge, ACM Digital Library, IGLC's and Stanford's databases and public and private associations. The terms "BIM", "VDC" were used in combination with "Lean". The papers were divided according to their methodology: surveys/interviews, case studies, literature reviews and implementation guides. A total of 70 articles were reviewed (Mandujano et al. 2013) for the purpose of this paper, considering space limitations, only 30 were included. 40 articles were discarded for the reasons listed below:

- Articles were not considered to be research articles (lack of references, no discussion of theory or method, etc.).
- Articles just focused on VDC implementation without mention the importance and connection with Lean.
- Based on Sacks et al. (2010a) we focused on the articles whom showed new interactions between VDC and Lean.

The literature on the implementation and impact of the models VDC has covered many important aspects, including but not limited to: benefits, obstacles, synergy between Lean/VDC, current status, implementation strategies and impacts of VDC in the AEC industry. Although studies cover to a greater or lesser extent all issues presented in Table 1, for the analysis we will focus on the core issue of each investigation. The following Table shows the main topics presented in the literature.

Table 1: Main topics presented in the literature

Methodology	Author(s)	Country	Benefits	Challenges	Lean/VDC	Current State	Strategies	KPI's/VDC	Impacts
Permanent online survey	Kunz and Gilligan (2006)	USA	o	o		o	o		o
Online survey and questionnaire	O'Ryan (2011)	Chile	o	o	o	o	o		o
Online survey, interview, case study	Gilligan and Kunz (2007)	USA	o	o	o	o	o		o
Interview, literature review, data	Ningappa (2011)	USA	o	o	o	o			o
Case study and survey	Rischmoller et al. (2006)	Chile	o		o	o			o
Case study	Khanzode et al. (2006)	USA	o		o	o	o		o
	Khanzode et al. (2007)	USA	o		o	o	o		o
	Enache et al. (2010)	USA	o		o	o	o		o
	Kala et al. (2010)	USA	o	o	o	o	o		o
	Khanzode (2010)	USA	o	o	o	o	o		o
	Kong (2010)	China	o	o		o			o
	Gerber et al. (2010)	USA	o	o	o				o
	Kala et al. (2010)	USA	o	o	o	o			o
	Arayici et al. (2011)	UK	o	o	o	o	o		o
	Crotty (2011)	UK	o	o	o	o	o	o	o
	Gao (2011)	USA	o	o	o	o	o		o
	Hardin (2011)	USA	o	o	o	o	o		o
	Reddy (2011)	USA	o	o	o	o	o	o	o
	Bhatla and Leite (2012)	USA	o		o	o			o
	Epstein (2012)	USA	o	o	o	o	o		o
	Hao (2012)	China	o		o	o			o
	Hamdi and Leite (2012)	USA	o	o	o	o	o		o
	Deutsch (2012)	USA	o	o	o	o	o		o
	Smith and Tardif (2012)	USA	o	o	o	o	o		o
	Tommelein and Gholami (2012)	USA	o		o	o			o
	Dave et al. (2013)	UK	o	o	o	o	o		o
	Sacks et al. (2012)	Israel	o		o	o	o		o
Literature review	Fischer et al. (2008)	USA	o		o	o	o		o
	Sacks et al. (2010)	Israel	o		o	o			o
Guidelines	USACE (2006)	USA	o	o	o		o	o	o

ANALYSIS OF VDC IMPLEMENTATION FROM A LEAN PESPECTIVE

Several studies have indicated that VDC's use is significant and rising (Gilligan and Kunz 2007, Kunz and Gilligan 2006). It has been reported that anecdotal evidence and beliefs about VDC implementation are insufficient for industry professional to formalize implementation guidelines and apply them throughout the project (Gao 2011, Gao and Fischer 2008). Moreover, it was concluded that VDC strategies and an implementation plan are crucial to achieve organizational goals. VDC models provide a framework to describe, monitor and manage changes to the product, process and organization throughout the project cycle (Kunz and Fischer 2011). To address this gap several studies have examined how to implement VDC within the AEC industry (Fischer and Kunz 2004, Gao 2011, Gao and Fischer 2008, Kong 2010, Kunz and Fischer 2011, O'Ryan 2011).

Previous researches show synergies between VDC and Lean (Arayici et al. 2011, Bhatla and Leite 2012, Enache-Pommer et al. 2010, Gerber et al. 2010, Hamdi and Leite 2012, Hao 2012, Khanzode 2010, Khanzode et al. 2007, Ningappa 2011, Sacks et al. 2012, Sacks et al. 2010a, Sacks et al. 2010b, Sands and Abdelhamid 2012, Tommelein and Gholami 2012). One study found that Computer Advanced Visualization Tools (CAVT's) implementation resulted in waste reduction and improved the customer value, indicating a strong synergy between Lean and CAVT (Rischmoller et al. 2006).

Sacks et al. (2010a), created a matrix of how Lean principles and BIM capabilities work together. This matrix can be use as a basis for creating lean and BIM adoption strategies. The authors concluded that there is a strong synergy and a high interaction between the Lean Construction principles and the BIM functionalities. Khanzode et al. (2006), emphasized that Lean Project Delivery System (LPDS) provides a framework for structuring the project implementation process, but does not provide tools to achieve the objectives of a lean production system. The tools, technologies and methods of VDC provide the best set to achieve the ideals of the LPDS. It has been found that early VDC implementation allows a better workflow (Kala et al. 2010) and the ability to coordinate work in the execution stage (Gilligan and Kunz 2007).

The Construction Users Roundtable (2010), indicated, "BIM facilitates leaner construction processes that directly impact the way subcontractors and fabricators work in four ways: greater degrees of prefabrication, improved workflow stability, enhanced teamwork, reduced inventories of engineered -to- order components. Moreover, BIM implementation not only automates the processes, but creates a leaner project (US Army Corps of Engineers (USACE) 2006).

Hamdi and Leite (2012), argued that to achieved the Lean principles through BIM depends on the level of skill of the people involved in BIM manipulation and execution.

Despite the high interest in the VDC use, few projects have properly implemented because there are still obstacles to their full implementation. Some of the obstacles most mentioned in the literature (Table 1) are: lack of implementation VDC guidelines, cultural barriers, lack of interoperability, software and hardware issues, contractual and legal aspects, lack of training, lack of commitment, lack of client's request.

INTERACTIONS BETWEEN VDC AND LEAN

Through our review of the literature, we found 128 interactions (Mandujano et al. 2013) between VDC and Lean, 21 of them mentioned by Sacks et al. (2010a). For reasons of space, we only showed 20 interactions of 128 found. Some of the interactions mentioned in Table 2 are the ones Sacks et al. (2010a) noted as 'not yet available'.

Table 2: Interactions between VDC and Lean

	Explanation	Evidence from practice and/or research
1	"Co-locating the design and detailing teams where detailers worked side by side to construct designs virtually and were able to resolve conflicts and issues immediately, further facilitated a highly integrated project delivery (e.g. Big Room)".	(Khanzode et al. 2007; Khanzode et al. 2010; Gilligan and Kunz 2007; Arayici et al. 2011; Hamdi and Leite 2012; Tommelein and Gholami 2012; Sacks et al. 2012)
2	"BIM enables improved labor performance and productivity data to be captured for reuse on subsequent projects".	(USACE 2006; Gao 2011; Deutsch 2011; Hardin 2011; Epstein 2012)
3	"Specifications are stored in a computer database. They are used as an input that allows for a 100% specification driven and compliant design. Specifications are visualized in a computer interface linked to the model elements. The perfection of improved internal customer-supplier-relationships in the case study project contributed to reduction in variability and uncertainty, major causes of rework and waste in construction".	(Rischmoller et al. 2006; Epstein 2012; Crotty 2011).
4	"Numerous commercial packages are available for visualization of construction schedules. Some automate the generation of construction tasks and modeling of dependencies and prerequisites by using libraries of construction method recipes, so that changes to plans can be made and evaluated within hours".	(Bhatla and Leite 2012; Gao 2011)
5	"Even after the construction phase, the facility operator for asset management, space planning, and maintenance scheduling to improve the overall performance of the facility or a portfolio of facilities can use valuable information".	(Ningappa 2011)
6	"The mode of supply management of a construction project can also be changed with the application of BIM, and the resources arrangement on site can be more accurate with the project schedule to achieve the object of zero inventories".	(Ningappa 2011)
7	"BIM interfaces provide a real time status reporting, measuring performance becomes accurate and feasible. Measurement of performance within a system where work is standardized and documented is central to process improvement". (Sacks et al. 2010)	(Hao 2012; Epstein 2012; Hardin 2011; Deutsch 2011; Crotty 2011; Reddy 2011).
8	"Detailed planning and generation of multiple fine-grained alternatives can be said to increase complexity rather than simplify management". (Sacks et al. 2010)	(O'Ryan 2011; Crotty 2011)
9	"Multiple users working on the same model simultaneously enables sharing of the workload". (Sacks et al. 2010)	(Deutsch 2011; Hardin 2011; Dave et al. 2013; Kong 2010; Gao 2011)
10	"Total project performance is improved and managed. By making specialists in design, supply and assembly work closely together, value is delivered to the customer and waste is reduced".	(Deutsch 2011; Hardin 2011; Enache 2010; Smith and Tardif 2012)
11	"The performance organization modeling can help to identify the need for protective buffers to avoid variability".	(Fischer et al. 2008)
12	"Foster more collaborative contractual relationships".	(Gao 2011)

	Explanation	Evidence from practice and/or research
13	"Facilitate the generation of building product specifications early in the design phase (by integrating standard product libraries to the design in BIM)".	(Gao 2011)
14	"Facilitate the process for homebuyers to compare alternatives and make the decision to buy".	(Gao 2011)
15	"Facilitate the management of owner-initiated change orders (by quickly showing the cost impact of these change orders and improving the accuracy of Bills of Quantities)".	(Gao 2011)
16	"Facilitate the performance reporting for facility managers to steer the building operation (conformance to targets) with the help of clearly documented performance metrics."	(Gao 2011; Kunz and Gilligan 2006)
17	"Reduce the amount of material stored on site (by reducing the batch size of shop drawings and placing procurement orders more frequently). Direct transfer of fabrication instructions to numerically controlled machinery, such as automated steel or rebar fabrication, eliminates opportunities for human error in transcribing information and automated generation of drawings, especially shop drawings for fabrication."	(Gao 2011)
18	"The deployment of 3D modeling eliminates unnecessary repetitive work. Therefore, one internal motivation of using 3D models in architectural firms is to make the design process more efficient."	(Gerber et al. 2010; Ningappa 2011; Hardin 2011; Crotty 2011)
19	"Abuse of the ease with which drawings can be generated can lead to more versions of drawings and other information reports than are needed being prepared and printed, unnecessarily increasing drawing inventories." (Sacks et al. 2010)	(Gilligan and Kunz 2007; Gao 2011).
20	"The Vico Virtual Construction Suite software is an integrated 5D system, which connects 3D models to a database for quantity takeoff, and enables the planning of locations to support location-based planning and scheduling. It is easier to visualize quantities, and to integrate quantities to schedule and cash flow."	(Kala et al. 2010)

SINERGY BETWEEN VDC AND LEAN

Hamdi and Leite (2012) stated that although BIM is considered a support tool for Lean, there are mutual interactions between both approaches in a two-way direction. VDC involves much more than simply implementing new software, is a new way of working. This requires a move away from the traditional workflow, with all parties sharing, and effectively working on, a common information pool. Lean implementation involves three components (Figure: 1). Philosophy and culture have high synergies between Lean and VDC, management principles and the big ideas in general are common: collaboration in design and construction, optimization of the whole system and participation and involvement of the end users area all facilitated by VDC in lean implementation. Lean Project Delivery promotes early involvement of all parties and concurrent design of all aspects of the project which is also the goal of VDC. On the other hand, VDC provides powerful technology to sustain the Lean Implementation effort. VDC helps to achieve the lean principles. VDC goes long away to removing wastes (Khanzode et al. 2007) but also improves workflow for many actors, even if they make no direct use of VDC (Eastman et al. 2008). VDC encourages and provides a path for the sharing of information between the stakeholders. The fact is that VDC and lean go together. One enables the other: the technology enables the process, makes it likely, possible, and even necessary (Deutsch 2011).

Although both approaches can be carried out independently to reach a higher potential is necessary to consider the three components jointly. This creates a greater potential of VDC and Lean implementation than the sum of its parts and consequently project performance is improved.

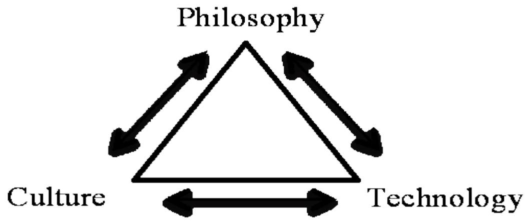

Figure 1: Lean/VDC implementation components

KEY DEFICIENCIES WITHIN THE LITERATURE

Despite the great efforts made by the different studies there is still a gap in the implementation process. Although multiple studies mentioned the quantitative or qualitative results related to VDC implementation most of these are still based on case studies. There is a need for systematic methods that enable companies of Architecture, Engineering and Construction (AEC) to identify the best VDC and Lean implementation strategies as well as their impact on the results of the company and the project.

CONCLUSIONS

The results highlight the importance of the VDC implementation, the lack of tools to identify strategies for successful implementation and the connection between VDC and Lean. The new interactions found in the literature can help to complete the matrix proposed by Sacks et al. (2010a) and, thus, create new implementation strategies.

Furthermore, it is necessary to understand how the synergy works between both approaches. As mentioned before, although both approaches can be carried out independently to reach a higher potential is necessary to consider the three components jointly. Only in this way we could take advantage of all the benefits that VDC and Lean offer jointly. For reasons of space, we didn't show all the interactions and the matrix based on Sacks et al. (2010a) but the article shows the current state of the VDC implementation from a Lean perspective.

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