Identifying waste in virtual design and construction practice from a Lean Thinking perspective: A meta-analysis of the literature

Identificación de desperdicios en la práctica del diseño y construcción virtual desde una perspectiva Lean Thinking: Un meta-análisis de la literatura

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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 Lean Construction methods, to deliver value to their customers. VDC includes the use of Production Management using Lean methods as an integral part of the defining theory and method, and multiple case studies have concluded that the greatest performance improvement is achieved by implementing both initiatives together. This paper reviews extensive literature of VDC and Lean Construction with the intent to show benefits in the application of Lean Construction in the actual practice of VDC and to provide examples of waste and opportunities for improvement in projects if Lean methods are applied. This study found that use of Lean methods can help to reduce waste within the VDC process, in the phase of information flow (process view). Specifically, our main finding from this study was that only five types of waste represent 80% of the referenced occurrence of waste in VDC processes, which suggests that if teams use Lean Methods and focus on elimination of these types of waste (i.e., motion (excess), inventory (excess), overproduction, waiting and employee knowledge (unused)), teams can improve VDC practices dramatically.

Keywords: VDC, Lean Construction, strategies, waste, BIM.

Resumen
En la actualidad, la industria de la Arquitectura, Ingeniería y Construcción (AEC) ha expandido el uso de los modelos virtuales de diseño y construcción (VDC), particularmente la metodología de *Lean Construction*, con el fin de entregar valor a sus clientes. VDC incluye el uso de la administración de producción usando los métodos Lean como una parte integral teórica y metodológica, y múltiples casos de estudio han concluido que las más grandes mejoras de desempeño se logran mediante la implementación de ambas iniciativas en conjunto. Este estudio exploratorio revisa la literatura acerca de VDC y de *Lean Construction* con la intención de mostrar los diferentes beneficios que se obtienen con la aplicación de Lean en la práctica actual de VDC. El estudio encontró que el uso de la metodología Lean puede ayudar a reducir los desperdicios dentro de VDC en la fase de flujo de información (enfoque de proceso). Específicamente, nuestro principal resultado de este estudio fue que sólo cinco tipos de desperdicio representan el 80% de las ocurrencias de desperdicio dentro del proceso de VDC, lo que sugiere que si el equipo del proyecto usa la metodología Lean y se enfoca en la eliminación de esos desperdicios (exceso de movimiento, exceso de inventario, esperas, sobreproducción y desperdicio del conocimiento del equipo), la práctica actual de VDC puede mejorar dramáticamente.

Palabras claves: VDC, Lean Construction, estrategias, desperdicio, BIM.

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 (Concha, Alarcón, & Mourgues, 2015). Virtual Design and Construction (VDC) and Lean Construction allow the construction industry to face different challenges (Khanzode, Fischer, Reed, & Ballard, 2006; Lee & Eastman, 2008). Multiple investigations converge in the potential that is achieved by implementing both initiatives together (Gerber, Becerik-Gerber, & Kunz, 2010; Sacks, Koskela, Dave & Owen, 2010a). While VDC and Lean Construction, have brought great benefits to the Architecture, Engineering and Construction industry (AEC), it appears that some efforts have focused on seeing Lean Processes as an approach merely for production (Rischmoller, Alarcón, & Koskela, 2006). Using evidence from the literature, we found several waste areas within VDC application that have been identified. This research aims to focus on the impact that Lean thinking has to reduce waste in project information flows. As a starting point, we define the two concepts for the specific purposes of the study:

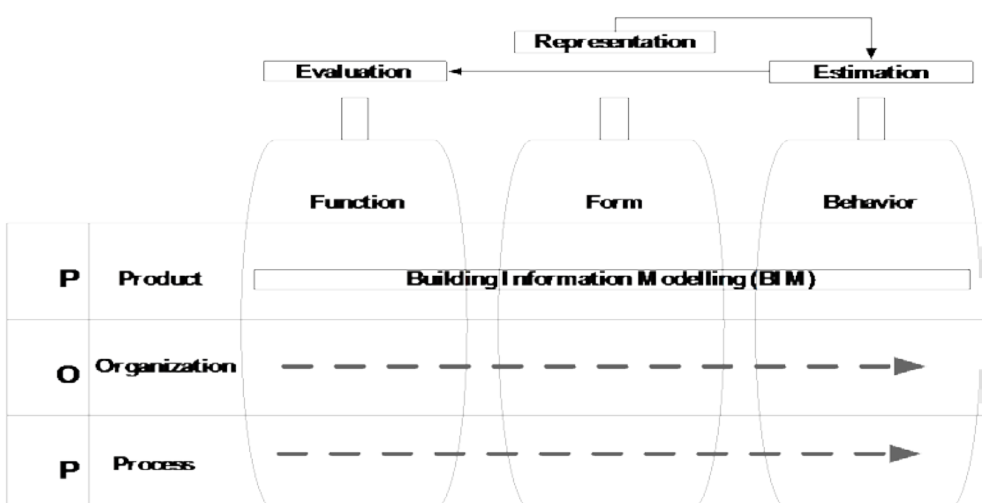
Virtual Design and Construction

Kunz & Fischer (2011) define 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 includes stakeholders and information flows among them that can be modeled and represented in a computer using symbolic representations of Products, Organizations, and Processes (P-O-P) (Khanzode et al., 2006). VDC allows building models of P-O-P early before a large commitment of time or money is made to a project (Khanzode et al., 2006).

VDC methodology includes use of Building Information Modeling (BIM). Researchers have viewed and defined BIM from different perspectives. (Eastman, Teicholz, Sacks, & Liston, 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.

VDC methods include BIM, Integrated Concurrent Engineering (ICE), metrics and lean-based production management. There is an explicit process to apply VDC: Plan (use of one or several of the methods), Do (apply the method), Check (that the BIM or ICE session of plan conforms to plan) and Act, i.e., take next steps. Although sometimes the terms VDC and BIM are used interchangeably, BIM represents the form/scope of the product, which is crucial but only one part of the VDC framework (Kunz & 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 (Figure 1). BIM relates to other methods and tools such as production models, critical path method (CPM) schedules, decision models, 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)).

Figure 1. The three components of the P-O-P framework. Source: Alarcón & Mourgues, 2010.

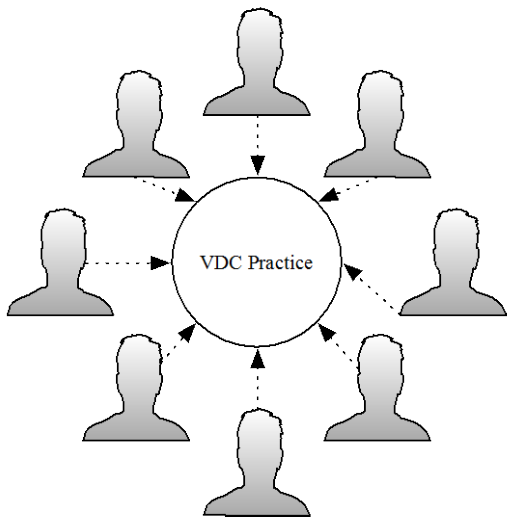


In this analysis, we focus on VDC as a process. A process is a structured, measured set of activities designed to produce a specified output. It implies a strong emphasis on how work is done within an organization, especially the "Plan" and "Check" activates, in contrast to a pure product focus emphasis 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 minimize or remove waste. Instances of waste can be found at any stage of the project, from the beginning of design through the construction phase. The more waste is eliminated, the better the results (Plenert, 2011). 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), this paper suggests that Lean Construction methods can help to reduce waste in the information flow (process view) of VDC practice. Figure 2 shows the graphical representation of waste in VDC practice.

Figure 2. Waste between VDC practice. Self-elaboration.



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 & 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.

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 & Tapping, 2005).

For this exploratory research, we did a survey of many public and private databases to identify relevant studies. These research studies showed different problems encountered during the use of VDC. Many organizations believe the problems of working in silos and having badly coordinated documentation will be greatly reduced through the adoption of BIM (Hamil, 2012). However, BIM is not a panacea for the fragmented building delivery processes (Gong & Lee, 2011). The National Institute of Building Sciences, 2007 defined BIM scope's under three categorizations: as a product or intelligent digital representation of data; as a collaborative process; and as a facility lifecycle management tool of well understood information exchanges, workflows, and procedures that teams use throughout the building lifecycle.

However, in order to optimize the use of BIM, it is critical that much of these data be shared between team members at different phases of the lifecycle of a facility (Beaven, 2011). Here, the interoperability issues emerge. Lack of interoperability affects the workflow in the BIM process and ultimately impacts a project's budget (Young Jr., Jones, & Bernstein, 2007). Re-entering data from BIM into another application used by the team creates wasteful and costly duplication of effort. McGraw-Hill, 2007 also reported that manually re-entering data from application to application was the biggest cost associated with interoperability. Other costs include time spent using duplicate software, time lost to document version checking, and increased time processing requests for information. A lack of interoperability hampers that exchange, leading to redundant work and a need to invest time and money in non-standard solutions that drive up project costs (Young Jr., Jones, & Bernstein, 2009).

BIM process data flows are varied and include the transfer of structured/computable, semi-structured, or nonstructured/non-computable data between computer systems (Halfawy & Froese, 2002). As such, BIM data flows do not only include sending and receiving 'semantically rich' objects, but also the sending and receiving of document-based information (Succar, 2009). The data flow can help by managing and communicating electronic product and project data among collaborating firms and by implementing and managing collaborative relationships among members of cross-disciplinary build teams that enable integrated project execution (Young Jr. et al., 2007).

The Institute for BIM in Canada, 2011 concluded that the BIM environment reduces the need for different types of paper documents. They also stated that the quality of communication between stakeholders is crucial for enabling the effective use of BIM. Normally, the design team exports every object with every possible attribute from the designer models; there can be just too much data. Very large amounts of data can be overwhelming and sometimes unnecessary (Jellings, 2012). As a solution, Reddy, 2011 mentioned that owners should provide specifications in the area of data standards. Data standards are very important for developing key performance indicators (KPIs) and benchmarking. Data can become very complex, and adherence to a standard simplifies the process. The National Institute of Building Sciences, 2007 emphasized that information has to be added by the party, creating the model before the receiving party can see it. To avoid frustration, the team should start the project by agreeing on what information will be added to the model and when. Each party can then plan its work, knowing what and when to provide and to expect information through the model. Such process planning will avoid duplication, enable efficiencies, and realize the benefits from BIM adoption.

VDC is an integrated approach that requires the implementation of multiple and ever-changing relationships among project stakeholders with responsibility for the Plan, Do, Check and Act steps of each VDC element, i.e., the BIM, production plans, use of Integrated Concurrent Engineering (ICE) and metrics that pertain to project and client target performance values and performance. Each of these VDC elements uses technology tools, but their use is a social process.
VDC processes include a series of decisions about specification, generation and certification of the usability of information. This process must be efficient to be effective. Once a VDC process is efficient, an organization can then think of achieving other results (product view). The aim is to deliver higher value to the customer, and we must start from the root problem. How VDC can use Lean principles, and the interactions between VDC and Lean Construction, are well documented (Arayici et al., 2011; Dave, Koskela, & Kiviniemi, 2013; Enache-Pommer, Horman, Messner, & Riley, 2010; Sacks, Radosavljevic, & Barak, 2010b).

Notwithstanding all the efforts that have been made, the literature does not explicitly examine how Lean Construction can help achieve a more efficient VDC process. Lean has a focus on production, and VDC theory considers the production of information; for example to specify, create, check and use models for physical construction during fabrication as well as on the job site. The goal of Lean is waste reduction, increased customer value, and continuous improvement. Just as Edwards Deming said, "It is not enough to just do your best or work hard. You must know what to work on." VDC is more than a technology; it has something in common with IT. Both are based on a series of tools, in which the information flows and waste are intangible unless budgeted and measured, in which case it is invisible to workers, project and senior management, i.e., invisible in practice, and generally neither noticed nor managed. In a physical environment, typical waste can often be observed easily, but in a VDC environment, process waste is historically difficult to identify and eliminate. For firms to be successful in the long term, they will need to demonstrate what value they can add and what they can do with their models (Hodges, Darling, & Cone, 2012). Koskela, 1992 defined waste as an: "Activity that takes time, resources or space but does not add value". We pose the following question: How can Lean Construction help to reduce or eliminate waste in VDC use?

Methodology

The research method for our study was a broad survey and a meta-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, Greenland, & Lash, 2008). Our analyses depend on the accuracy and thoroughness of the published studies we reviewed. For this paper, we attempted to gather 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 were available in the databases. Our research method includes the following stages:

- Defining a question and agreeing an objective method.
- A search for relevant data.
- Extraction of relevant data.
- Assess the quality of the data.
- Analyze and combine the data.

Search Procedures

An extensive search of construction and related literature was initiated by manual and computer searches of <28> two major online databases (ASCE and Science Direct), paper congress, and guidelines, which we reviewed from 2001 to present. (Table 1). Each study was subjected to inclusion rules for aggregation. A study was included if:

- The studies were published by reputable sources.
- The studies reported types of waste within current VDC practices on the information flow.

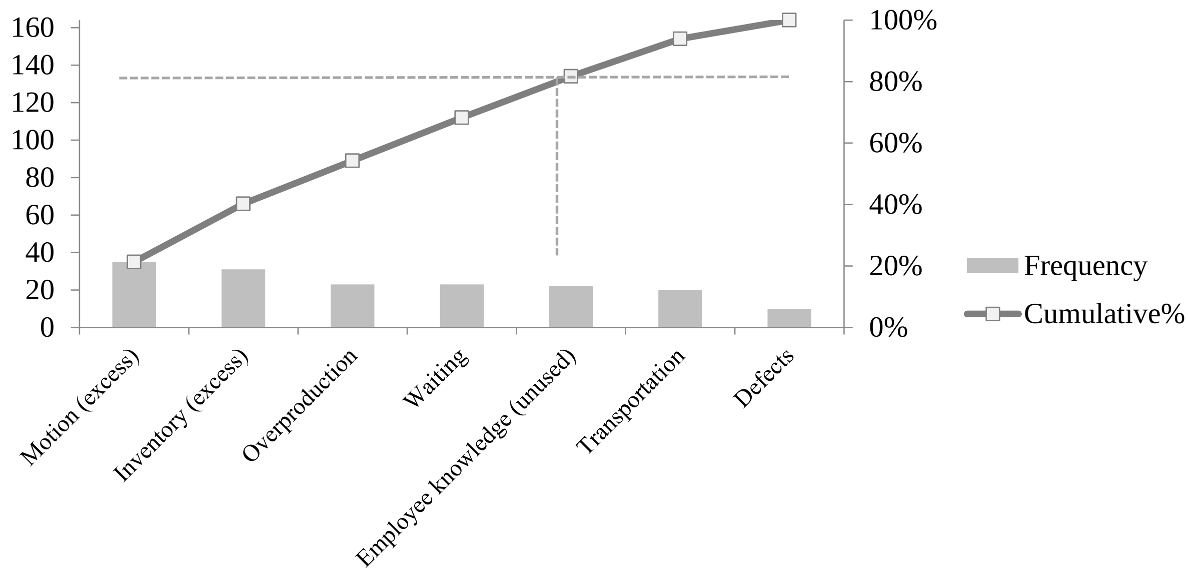
Table 1. Number of references to waste in projects that reported VDC use. Self-elaboration.

ID	REFERENCES	NO. OF WASTE MENTIONED
1	Staub-French & Khanzode, 2007	4
2	Anderson, Marsters, Dossick, & Neff, 2012	4
3	The CRC for Construction-Innovation, 2009	3
4	Singh, Gu, & Wang, 2011	3
5	Al-Sadoon & Rahman, 2010	2
6	Bernstein & Pittman, 2004	2
7	DesignBuild, 2012	2
8	Prather, 2015	2
9	Chobot, 2011	2
10	Madsen, 2008	1
11	Oakley, 2012	1
12	The Associated General Contractors of America, 2006	1
13	McGraw-Hill, 2007	1
14	The National Institute of Building Sciences, 2007	1
15	Arayici, Coates, et al., 2011	1
16	Wang, Love, & Davis, 2012	1
17	Autodesk, 2010	1
18	The Construction Users Roundtable, 2010	1
19	Schwegler, Fischer, O'Connell, Hänninen, & Laitinen, 2001	1
20	Hartmann, Goodrich, Fischer, & Eberhard, 2007	1
21	Fallon & Palmer, 2007	1
22	Kulahcioglu, Dang, & Toklu, 2012	1
23	Statsbygg, 2013	1
24	Khanzode, 2015	1
25	Benson & Hartzog, 2009	1
26	Building and Construction Authority, 2012	1
27	Al-Mannai, n.d.	1
28	Sacks et al., 2010a	1

After the extensive search, we analyzed references to waste and classified these occurrences into seven types of waste reported in the literature: Motion (excess), Inventory (excess), Waiting, Overproduction, Employee knowledge (unused), Transportation/Navigation, and Defects. In the twenty-eight papers we analyzed, we found forty-three references to waste in the implementation of VDC (Due to space only ten references to waste are mentioned. The full list of interactions of Table 3 can be accessed at: Mandujano, 2015.

Figure 3 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 use Lean methods and focus on elimination of these types of waste (Motion (excess), inventory (excess), overproduction, waiting and employee knowledge (unused), they can improve VDC practices dramatically.

Figure 3. Pareto Chart about VDC waste. Source: Self-elaboration.



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 & 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 recommendations to reduce these kinds of waste within the VDC information flow (Kremer & Tapping, 2005; Pestana, 2011; Ryan, 2010).

Table 2. Reducing waste within the VDC information flow using Lean Methods. Source: Self-elaboration.

TYPES OF WASTE FOUND IN THE LITERATURE	HOW LEAN CAN HELP TO REDUCE THIS WASTE
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)	Gathering people and/or processes in order to improve workflow (cellular manufacturing): • Protocols for sharing models. • BIM libraries. • Meeting and quality protocols.
WAITING	• Development of a communication plan.
OVERPRODUCTION	• Use Value-Stream Mapping (VSM).
EMPLOYEE KNOWLEDGE (UNUSED)	• Promote normalized coaching and mentoring skills, rotations, strategic tasks and competency assessments. • Create mechanisms to capture, communicate and apply experience-generated learning and checklists (lessons learned).
TRANSPORTATION/NAVIGATION	• Develop 5S plans.
DEFECTS	• Use simple, grass-roots level suggestions to eliminate waste.

Discussion

Although studies have been performed about the connection between VDC and Lean Construction (Arayici et al., 2011; Dave et al., 2013; Enache-Pommer et al., 2010; Sacks et al., 2010b), this article reports and discusses a part of VDC practices that has not been systematically studied: waste within the application of VDC. Our literature survey finds many references to waste in the VDC literature, which suggests that waste exists in current practice. We suggest that current practice is a root cause of the waste problem, and Lean methods can help to address that problem. We suggest that it is crucial for the AEC industry to think seriously about the methods of VDC implementation, specifically to focus on the method and not on a specific technology.

The application of VDC can build on a Plan-Do-Check-Act cycle (McComb, 2008) in which the Plan steps are defined as Lean-based production plans and the Check steps are Lean-inspired checks that the work done in the Do step aligns with the planned specification. Examples of the Check step include quality conformance of BIMs and installed work, cost conformance to daily and milestone budgets and schedule conformance, or Planned Percent Complete (PPC). A company should empower stakeholders to formalize the process of VDC and then later automate all tasks.

This exploratory literature suggests that VDC practice is informal and frequently include waste as viewed from a Lean Thinking perspective. VDC practitioners may benefit from careful attention to their VDC management processes to reduce waste. Eighty percent of the literature references reported five types of waste, suggesting that if project teams focus on eliminating those five types, they can improve VDC practices dramatically. The five types of waste are: Motion (excess), Inventory (excess), Waiting, Overproduction and Employee knowledge (unused).

Many Lean Methods are available to help the AEC industry to reduce waste in its VDC implementation. For example, value-Stream Mapping (VSM), a method to analyze 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 reduce excess inventory and to develop Knowledge Management Strategies (Arriagada & Alarcon, 2013).

This research 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.

Furthermore, profitability is becoming increasingly difficult to preserve, and production challenges directly impact margins. VDC is an initiative that offers huge potential benefits to the AEC industry. Information flows throughout all VDC processes, and these processes must be efficient in order to achieve better results. It is unwise to think of Lean Construction only at the production phase or as an initiative that helps VDC to achieve better results. Lean Thinking can go through every single phase of VDC methodology. It allows the specification of how to carry out a process, and VDC ensures that processes work consistently.

Conclusions

This exploratory research found reported occurrence of waste in current VDC practices. There are big opportunities for project teams to introduce Lean Methods in VDC practice, with the goal to reduce waste and create a more efficient VDC processes. The synergy between Lean Construction and VDC is not new. Multiple investigations concur on the potential that is achieved by implementing both initiatives (Dubler, Messner, & Anumba, 2010; Sacks et al., 2010a). Furthermore, VDC provides the means and methods to implement Lean Principles and incorporate management principles that help to eliminate waste, reduce costs, improve productivity, and create positive results for projects. The literature survey suggests that VDC practice is informal and VDC practitioners may benefit from careful attention to their VDC management processes to reduce waste. If Lean principles, systems and tools are applied through every single phase of VDC practice the AEC industry can take better advantage of both powerful approaches to design and construction. The results presented in this paper are part of an ongoing research project on VDC implementation strategies; future research will further explore VDC implementation approaches using the Lean Thinking perspective.

Acknowledgments

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Table 3. Evidence of waste in VDC Practice. Source: Self-elaboration.

	EVIDENCE FROM ACTUAL PRACTICE AND/OR RESEARCH	DEFECTS	OVERPRODUCTION	WAITING	TRANSPORTATION	INVENTORY (EXCESS)	MOTION (EXCESS)	EMPLOYEE KNOWLEDGE (UNUSED)
1	What usually happens within projects is that specialists create redundant and inconsistent documents, so time is wasted (Madsen, 2008).			●	●		●	
2	In many cases, companies spend thousands of dollars on software and BIM training, then leave the project and the investment is wasted (Oakley, 2012).					●	●	●
3	The amount of redundant effort required developing and maintaining the various databases of the specialist that employ BIM represents the greatest source of waste and error associated with BIM implementation (The Associated General Contractors of America, 2006).		●			●	●	
4	Interoperability issues are gaining a lot of attention with the progressive use of BIM. Re-entering from BIM into another application or platform can be a costly and wasteful duplication (Al-Sadoon & Rahman, 2010).					●		●
5	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 (Young Jr. et al., 2007).	●	●	●		●	●	
6	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 (National Institute of Building Sciences (NIBS), 2007).	●	●			●	●	
7	The methods of sharing outputs and interaction with other consultants within the team were also critical (Arayici, Kiviniemi, et al., 2011).			●	●		●	●
8	Carrier mechanisms—the methods for sharing computable information between applications and processes—may become more important than the data itself (Bernstein & Pittman, 2004).				●	●	●	
9	Improve efficiencies of delivery. Designers and contractors should be encouraged to eliminate redundant work processes through close collaboration. Re-definition of traditional delivery roles could be required (The Construction Users Roundtable, 2010).		●			●		●
10	The goal is to reduce the number of redundant tasks and to bring the necessary stakeholders on board at the right time to enable the generation of project information that can be shared electronically with others in the same phase and throughout the future phases of a project (Schwegler et al., 2001).	●				●	●	

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