A STRUCTURED LITERATURE REVIEW: VALUE STREAM MAPPING (VSM) IN CONSTRUCTION INDUSTRY

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ABSTRACT

For the past few years, almost every sector of the manufacturing and service industries have applied some form of lean methodology. Likewise, lean-based tools have been applied to simple and complex construction projects. Value stream mapping (VSM), as a lean tool for manufacturing, is used as a basic graphical tool that aims to describe production processes and to identify and reduce types of waste. In its current state, VSM is not being implemented as successfully in construction as it is in manufacturing due to fundamental differences between manufacturing and construction. This paper's methodology uses a structured literature review to summarize the current state of VSM application in construction industry. By finding the connection among the current research will enable the adaptation of VSM for use in the construction industry and provide a theoretical framework of the applications of VSM in construction for further research.

Keywords: Value Stream Mapping, VSM tools, VSM in construction, application of VSM, application of VSM in construction

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Nomenclature

Definitions

- **Lean manufacturing**: a production practice that regards the consumption of resources for any objective other than the making of worth for the end client to be inefficient, and in this way, an objective for elimination (Liker, 2004).
- **Value Stream:** the arrangement of activities needed to design, produce, and convey a product or service to a client; incorporates material flow and information flow (Womack & Jones, 2002).
- **Value Stream Mapping (VSM):** a lean-management method that aims to bring a product or service from productive beginning to the end customer by analysing the current state and designing a future state for the series of events (Rother, Shock, Womack & Jones, 2003).
- **Value Stream Mapping Tools (VALSAT):** seven tools: process activity mapping; supply chain responsiveness matrix; product variety funnel; quality filter mapping; forester effect mapping; decision point analysis; overall structure maps (Hines & Rich, 1997).
- **MUDA**: derived from a Japanese word signifying "vanity; futility; absence of movement; pointlessness; waste; wastage; inefficiency"; a key concept in the Toyota Production System as one of three types of deviation from an ideal distribution of resources (Emiliani, Stec, Grasso & Stodder, 2007).
- **Takt Time:** originated from the German word Taktzeit, sets the pace for industrial manufacturing lines with the goal that cycle times can be coordinated to client interest rate (Liker, 2004).

INTRODUCTION

1.1 Background

The construction industry has been criticized and compared to manufacturing by governmental publications and society for low production efficiency, low quality, natural resources waste and the high rate of work accidents during the production process and operating performance. For improving quality, efficiency, and reducing waste, Lean Thinking philosophy has been imported into the construction industry since the 1970s (Fontanini, Milano, Fujimoto, Lintz, Gachet-Barbosa & Jacintho, 2013). Some successful experiences in implementing lean construction have been achieved: Conte and Gransberg (2001), for example, examined the principles used in applying lean construction by over 20 construction companies in Brazil.

Value stream mapping (VSM) originated in the Toyota Production System. VSM's functions are to both analyze and design the flow of material and information required to bring a product or service to the end-consumer (Rother et al, 2003). VSM has been used in factories that use visual work processes for finding waste created during their operations. VSM improves work strategies by developing a deeper understanding of the workflows through the entire systems, establishing a strategic direction for making improvements, and delivering value to the end users (Martin & Osterling, 2013).

According to Pasqualini and Zawislak (2005), the philosophy of lean production and the principles of VSM have been applied to construction since 1993. However, the application of VSM in construction has focused on specific areas. An in-depth literature review shows that previous studies on the application of VSM in construction have focused only on macro-processes such as supply chain (Arbulu, Tommelein, Walsh, & Hershauer, 2003) or project delivery (Mastroianni & Abdelhamid, 2003), or on single operations such as components manufacturing (Alves, Tommelein & Ballard, 2005), and masonry works (Pasqualini & Zawislak, 2005). The application of VSM in construction has been very limited when compared with other industries.

1.2 Objectives

This paper has two objectives: to develop an in-depth understanding of the application of VSM in construction by using the Structured Literature Review, and to analyze what reasons hinder VSM application in construction.

1.3 Delimitations of the Study

The scope of the research is delimited to an in-depth literature review of previous studies on value stream mapping and especially the application of VSM in the construction industry. The literature search is limited to research written in English. Some valuable research may be excluded, due to being created in other languages.

METHODOLOGY

2.1 Introduction

Bernstein and Fink (1998) defined a literature review as: "A precise, unequivocal, and reproducible configuration for recognizing, assessing, and deciphering the current group of recorded writing". The analysis of literature helps researchers create a focused background in a field of interest. The literature review maps two sets of documents: first, they abridge existing research by distinguishing examples, topics, and issues. Second, literature reviews serve to distinguish the reasonable substance of the field and may add to theory improvement. The diversity of literature sources within the management disciplines has resulted in a growing need for a systematic methodology to map the territory of its associated theories and models. Compared with either a traditional or narrative review, a structured literature review is a more rigid, well-defined, and scientifically accepted method to review the literature by building on the method's criteria to identify, rate and synthesize all the literature in a particular research field.

This paper concentrates on VSM and its application in the construction industry. Although being successfully applied in the manufacturing industry, VSM's application in construction still has not fully been utilized (Arbulu et al, 2003). In order to build a theoretical framework, a comprehensive literature review is appropriate for understanding VSM in construction. The summary of previous research on the application of VSM will provide a larger picture of current research, identify, and understand the connections among them. Thus, developing a deeper understanding of how VSM may be leveraged in construction.

2.2 Database and Keywords

The databases used for the literature search include: Google Scholar, ASCE Library, Web of Knowledge, Construction Journal, Science Direct, and ProQuest Dissertations. In addition to the databases, the following books were used as references: "*The Toyota Way"*, written by Liker (2004), introduces lean principles and addresses VSM as a useful lean approach that can be applied across numerous industries. *Value Stream Mapping-How to Visualize Work and Align Leadership for Organizational Transformation"*, written by Martin and Osterling (2013), systematically introduces the definition of VSM and its application as a tool.

After determining the main databases, the next step is using keywords to refine the scope of the search for literature. A preliminary search of VSM yielded over 20,000 papers, and in order to narrow the scope, a set of keywords based on the main research question was used. For example, the following keywords proved useful: VALSAT, VSM in the construction, the application of VSM in the construction industry. After using different combinations of keywords, the resulting list was narrowed down to more than 1000 papers for "VALSAT", 107 papers with the topic of "value stream mapping in the construction", 10 papers for "the application of value stream mapping in the construction industry". The criteria for choosing the final analyzed literature focus on the research problem (related to the application of VSM in the construction industry), aims, research design and methodology, objectives, findings, and conclusions. Eventually, 17 separate works were selected as the final analyzed literature related to the research question. After identifying relevant studies, the papers, citations, and data were added into RefWorks, a web-based research management, writing, and collaboration tool. It helps researchers easily gather, manage, store, and share all types of information by importing references from text files, online databases, and other sources, as well as generate citations and bibliographies. In order to further analyze the literature, a Literature Selection Table was created. This table lists any papers relevant to the research and documents the reason for their selection. Table 1 shows a sample of the relevant literature papers.

Table 1. Sample of Literature Selection (see Appendix A for total list)

Survey of all literatures on the topic VSM					Applicable to research				
Item	Paper topic	Authors	Journal/citation of the publication	Year	YES	NO	MAYBE	Reason	Notes
1	The seven value stream mapping tools	Hines, P., & Rich, N	International Journal of Operations & Production Management	1997	x			An introduction of value stream mapping tools	vsm
2	An evaluation of the value stream mapping tool	Lasa, I. S., Laburu, C. O., & de, C. V	Business Process Management Journal	2008			x	using the vlaue stram mapping to redesign the production system	manufacturing
3	The application of value stream mapping to lean engineering	Pavnaskar, S. J., & Gershenson, J. K.	2004 ASME Design Engineering Technical Conferences and Computers and Information in Engineering Conference	2004		x		value stream mapping in the engineering process	
4	Value stream mapping: A study about the problems and challenges found in the literature from the past 15 years about application of lean tools.	Dal Forno, A. J., Pereira, F. A., Forcellini, F. A., & Kipper, L. M.	International Journal of Advanced Manufacturing Technology	2014			x	overview of application of vsm in different industries and its problems	vsm
5	Concrete slab value stream mapping of brazilian residential buildings - A lean construction study case.	Fontanini, P. S. P., Milano, C. d. S., Fujimoto, A., Lintz, R. C. C., Gachet-Barbosa, L., Jacintho, A. E. P. G. A., et al.	4th International Conference on Manufacturing Science and Engineerin	2013	x			vsm in the construction	construction
6	Adaptation of the value stream optimization approach to collaborative company networks in the construction industry.	Matt, D. T., Krause, D., & Rauch, R.	8th CIRP International Conference on Intelligent Computation in Manufacturing Engineering	2013	x			this paper describes in detail a methodology to design an integrated and customized value stream map for construction industries requirement	construction
7	The challenge: the impetus for change to lean project delivery	Remo Mastroianni1 and Tariq Abdelhamid2	Group for Lean Construction	2003	x			vsm in project delivery	construction

2.3 Analyze the Literature and Reference Matrix

Table 2 is a reference matrix that overviews, organizes and summarizes the readings. The matrix includes general information, keywords, aims, research methods, summary of research results, and useful references. When relevant references were identified, they were also added to the matrix.

2.4 Group the Literature and Findings from the Extant Studies

The objective of doing a literature review is to synthesize the literature into an integrated review. Tables 3 and 4 organize the literature into bibliography, themes, and keywords. According to the analysis of current literature, VSM is grouped into two different categories: VSM principles and tools; VSM in construction. VSM in construction mainly focuses on: macro-processes, construction support processes and the construction process. Tables 3 and 4 show the literature maps.

Table 2. Sample of the Reference Matrix (see Appendix B for total reference Matrix)

No	Title	Bibliography	Key words	Aims
1	The seven value stream mapping tools	Hines, P., & Rich, N	value stream mapping	The motivation behind this paper is to develop a typology to take into consideration a compelling utilization of sub-sets of the complete suite of tool and utilization of this suite of tools is to help researchers or professionals to distinguish waste in individual value streams and, hence, locate a proper course to removal, or possibly decrease, of this waste.
2	Concrete slab value stream mapping of Brazilian residential buildings: a lean construction case study	Patricia Stella Pucharelli Fontanini, Caroline de Souza Milano, Aparecido Fujimoto, etc.	value stream mapping Construction	This paper presents the value stream mapping could improve the production and environmental performance
3	Development of Lean Model for House Construction Using Value Stream Mapping	Haitao Yu; Tarry Tweed; Mohamed AL-Hussein and Reza Nasseri	value stream mapping Construction	Using VSM to improve the constructive process

Table 2 Continued

No	Research Methodology	Summary of Results	Useful References
1	Grounded Theory	Describes a toolkit consisting of seven tools: 1. overproduction 2. waiting for 3. transport 4. inappropriate processing 5. unnecessary inventory 6. unnecessary motion and 7. defects. The article discusses problems with existing tools for analyzing value streams. The main problem identified was that each of these tools was too limited in scope and did not integrate well with one another in order to provide a comprehensive view of the value stream. The seven tools presented in the article were specifically designed to eliminate this problem.	Womack, J. and Jones, D., “From lean production to the lean enterprise”, Harvard Business Review, March-April 1994, pp. 93-103.
2	Case Study	The execution of research started with the diagnosis of lean and sustainable concepts selected, and an analysis initial of the value stream mapping applicability in the concrete slab processes. This paper gave a case example of how VSM contributes to making decisions about the flow represented making it logical and simplified, the production process, addressing lean techniques and concept as a whole.	J.P. Womack: *the challenge of value stream management.* Lean Enterprise institute value stream management conference. Dearborn, 2000 M.Rother: *Crossroads: which way will you turn on the road to lean?* In: LIKER, J.K. (Editor)> Becoming lean: inside stories of U.S. Manufactures. Portland, Oregon, USA: Productivity press,1997
3	Case Study	Lean construction has recently attracted considerable attention in the home building industry. Lengthy delivery time and significant waste in the construction process have caused many home builders	Alves, T.C.L., Tommelein. I.D., and Ballard, G (2005). "Value stream mapping for make-to-order products in a job shop environment."

Table 2. Literature Map of VSM Principles and Tools

VSM PRINCIPLES AND TOOLS			
NO		***THEME***	***KEY WORDS***
1	Martin, K., & Osterling, M. (2013). Value stream mapping: how to visualize work and align leadership for organizational transformation.	VSM principles and application	How to visualize work and align leadership for organizational transformation
2	Rother, M., & Shook, J. (2003). *Learning to see: value stream mapping to add value and eliminate muda*	Value Stream Mapping Principles and Tools	Learning to See: Value Stream Mapping to Add Value and Eliminate MUDA
3	Hines, P., & Rich, N. (1997). The seven value stream mapping tools	Value Stream Mapping Tools	Contingency planning, Cross-functional integration, Process layout, Supply-chain management, Value analysis, Waste disposal

Table 3. A Literature Map of VSM in Construction

VALUE STREAM MAPPING IN CONSTRUCTION			
NO		***THEME***	***KEY WORDS***
1	Fernanda Pasqualiniand Paulo Antônio Zawislak.(2005). Value Stream Mapping in Construction: A Case Study in a Brazilian Construction Company	Construction process	Value stream mapping, Systemic implementation
2	Sergio Rosenbaum; Mauricio Toledo, ; and Vicente González.(2013). Improving Environmental and Production Performance in Construction Projects Using Value Stream Mapping: Case Study	Construction process	Management; Process control
3	Patricia Stella Pucharelli Fontanini; Caroline de Souza Milano;Aparecido Fujimoto;Rosa Cristina Cecche Lintz;Luísa Andréia Gachet-Barbosa; Ana Elisabete P.G. A. Jacintho; Lia Lorena Pimentel.(2013). Concrete Slab Value Stream Mapping of Brazilian Residential Buildings - A Lean Construction Study Case	Construction process	Lean construction, Value stream mapping, Concrete slabs, Lean tools
4	Haitao Yu; Tarry Tweed; Mohamed Al-Hussein; and Reza Nasseri.(2009). Development of Lean Model for House Construction Using Value Stream Mapping	Construction process	Buildings, residential; Housing; Lean construction; Production management; Construction

Table 4. Continued

NO		THEME	KEY WORDS
5	D.T. Matta,b, D. Krausea, R. Raucha.(2013). Adaptation of the value stream optimization approach to collaborative company networks in the construction industry	Macro-process	Value stream mapping design,Collaborative networks
6	Remo Mastroianni; Tariq Abdelhamid. (2005). The Challenge : The Impetus for Change to Lean Project Delivery	Macro-process	Lean Construction, Implementation, Organizational Change, Value Stream Mapping, Logistics Planning, Visual Management, 5S, Last Planner System
7	Patricia S.P.Fontanini; Flavio A. Picchi.(2004). Value Stream Macro Mapping-A Case Study of Aluminum Windows for Construction Supply Chain	Construction support process	Supply chain, Macro Mapping, Value Stream Mapping, Lean Thinking, Aluminum Supply Chain
8	Thais da C. L. Alves; Iris D. Tommelein;Glenn Ballard.(2005). Value Stream Mapping for Make-To-Order Products in A Job Shop Environment	Construction support process	Value Stream Mapping, HVAC sheet metal fittings, Make-to-order, Job shop, Lean Production, Lean Construction
9	Roberto Arbulu; Iris Tommelein; Kenneth Walsh;James Hershauer.(2002). Value stream analysis of a re-engineered construction supply chain	Construction support process	Construction performance, Lean project delivery system, Production management, Re-engineering construction, Supply chain management, Value stream mapping, waste

LITERATURE REREVIEW

This chapter summarizes the literature based upon two categories: VSM principles and tools, VSM in the construction industry.

3.1 Value Stream Mapping Principles and Tools

3.1.1 Value Stream Mapping Principles

VSM originates from Toyota's material and information flow diagrams and was designed to help Toyota's suppliers learn the Toyota Production System (Rother et al. 2003). Rother's study and ten years of experience in operating VSM in various industries have demonstrated that VSM is more than just a tool. VSM was not limited only to identifying waste in a system, but could also be used to analyze and aid in designing processes, tracing material flow, and documenting information flow of a given product or product family. VSM uses symbols to represent a clear and visual process from the customer's requirement to the final accomplishment. The tables 5 to 8 show the symbols of VSM.

Table 5. VSM Process Symbols (Strategos. (2007). Value Stream Mapping Symbols & Icons. Retrieved from: http://www.strategosinc.com/vsm_symbols.htm)

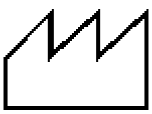
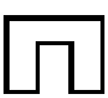
Symbol	Meaning
	Customer/Supplier Icon: represents the Supplier when in the upper left, customer when in the upper right, the usual end point for material
	Dedicated Process flow Icon: a process, operation, machine or department, through which material flows. Represents one department with a continuous, internal fixed flow
	Shared Process Icon: a process, operation, department or work center that other value stream families share
	Data Box Icon: it goes under other icons that have significant information/data required for analyzing and observing the system
	Work Cell Icon: indicates that multiple processes are integrated in a manufacturing work cell

Table 6. VSM Material Symbols (Strategos. (2007). Value Stream Mapping Symbols & Icons. Retrieved from: http://www.strategosinc.com/vsm_symbols.htm)

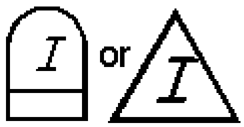
Symbol	Meaning
	Inventory Icons: show inventory between two processes

Table 6. Continued

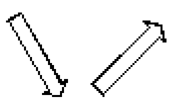
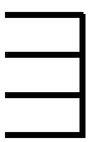
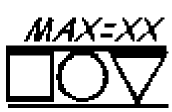
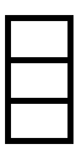
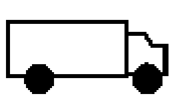
Symbol	Meaning
	Shipments Icon: represents movement of raw materials from suppliers to the receiving dock/s of the factory. Or, the movement of finished goods from the shipping dock/s of the factory to the customers
	Push Arrow Icon: represents the “pushing” of material from one process to the next process
	Supermarket Icon: an inventory “supermarket” (kanban stockpoint)
	Material Pull Icon: supermarkets connect to downstream processes with this "Pull" icon that indicates physical removal
	FIFO Lane Icon: First-In-First-Out inventory. Use this icon when processes are connected with a FIFO system that limits input.
	Safety Stock Icon: represents an inventory “hedge” (or safety stock) against problems such as downtime, to protect the system against sudden fluctuations in customer orders or system failures
	External Shipment Icon: shipments from suppliers or to customers using external transport

Table 7. VSM Information Symbols (Strategos. (2007). Value Stream Mapping Symbols & Icons. Retrieved from: http://www.strategosinc.com/vsm_symbols.htm)

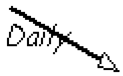
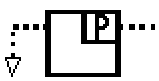
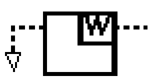
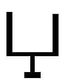
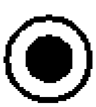
Symbol	Meaning
	Production Control Icon: represents a central production scheduling or control department, person or operation
	Manual Info Icon: A straight, thin arrow shows general flow of information from memos, reports, or conversation. Frequency and other notes may be relevant
	Electronic Info Icon: represents electronic flow such as electronic data interchange (EDI), the Internet, Intranets, LANs (local area network), WANs (wide area network). You may indicate the frequency of information/data interchange, the type of media used, ex. fax, phone, etc. and the type of data exchanged
	Production Kanban Icon: triggers production of a predefined number of parts. Signals a supplying process to provide parts to a downstream process
	Withdrawal Kanban Icon: represents a card or device that instructs a material handler to transfer parts from a supermarket to the receiving process. The material handler (or operator) goes to the supermarket and withdraws the necessary items.
	Signal Kanban Icon: used whenever the on-hand inventory levels in the supermarket between two processes drops to a trigger or minimum point. It is also referred as "one-per-batch" kanban.
	Kanban Post Icon: a location where kanban signals reside for pickup. Often used with two-card systems to exchange withdrawal and production kanban.
	Sequenced Pull Icon: represents a pull system that gives instruction to subassembly processes to produce a predetermined type and quantity of product, typically one unit, without using a supermarket

Table 7. Continued

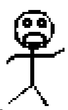
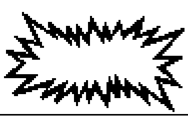
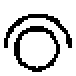
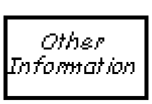
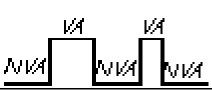
Symbol	Meaning
	Load Leveling Icon: a tool to batch kanbans in order to level the production volume and mix over a period of time
	MRP/ERP Icon: scheduling using MRP/ERP or other centralized system
	Go See Icon: gathering of information through visual means
	Verbal Information Icon: represents verbal or personal information flow

Table 8. VSM General Symbols (Strategos. (2007). Value Stream Mapping Symbols & Icons. Retrieved from: http://www.strategosinc.com/vsm_symbols.htm)

Symbol	Meaning
	Kaizen Burst Icon: used to highlight improvement needs and plan kaizen workshops at specific processes that are critical to achieving the Future State Map of the value stream.
	Operator Icon: represents an operator. Shows the number of operators required to process the VSM family at a particular workstation
	Other Icon: other useful or potentially useful information
	Timeline Icon: shows value added times (Cycle Times) and nonvalue added (wait) times. Use this to calculate Lead Time and Total Cycle Time.

There are five basic steps for applying VSM in various industries. The first step is to define the product or product family and then draw a current state map of the product. After identifying the non-value and value-added processes, the team brainstorms and combines lean concepts with the value added to construct a future state map. The last step is to implement an action plan with a detailed process map, and a yearly value stream plan that could achieve the future state.

3.1.2 Benefits of Value Stream Mapping

"Learning to See: Value Stream Mapping to Add Value and Eliminate MUDA" written by Rother et al. (2003) and "Value Stream Mapping: How to Visualize Work Flow and Align People for Organizational Transformation" written by Martin and Osterling (2013) present the following benefits of Value Stream Mapping:

(1) Provides a holistic view of the entire flow

By mapping the value stream, a better understanding of the whole process can be achieved. The act of connecting separate parts into a more holistic system helps the team to identify both the necessary and unnecessary functions, allowing the latter to be either removed or changed for better process flow. VSM also helps to discover any potential information problems that are not easily identified within the production system. Visualizing non-visible works such as information exchanges are important in understanding how work is accomplished.

(2) Identifies Waste

Applying VSM to map the current state of the product or service shows value added and non-value added processes and waste during the production process. What is more, the value stream map can clearly identify the seven most common types of waste: Overproduction, Waiting, Transport, Extra processing, Inventory, Motion, and Defects, all of which are summarized in Table 9.

Table 9. Seven Wastes

Waste	Example
Overproduction	Precast concrete is produced at a level higher than the owner required. This leads to waste and an increase in inventory and waiting time.
Waiting	Work will be delayed due to broken equipment, bad weather.
Transportation	Unnecessary movement of information, products or components from one place to another.
Extra Processing	Following the process accurately to eliminate potential costs in installation or rework.
Inventory	Unused products wait for further processing. Poor planning will increase cost of the worksite and occupy valuable warehouse space.

Table 9. Continued

Waste	Example
Motion	Poor material layout will produce unnecessary movements by workers on the work site.
Defects	Defective materials and damaged machines can lead to rework and increase costs.

(3) Generates improvement plans

Once wastes are identified in the production process, the team can start building an improvement plan using lean concepts to eliminate waste and to add value. VSM focuses on calculated experimentation in certain parts of the process before disturbing the flow of the rest of the business.

3.1.3 Value Stream Mapping Tools

Hines and Rich (1997) conducted a study describing the seven VALSAT in terms of the seven wastes mentioned above. The seven tools and their relationships are shown in Table 10 below.

Table 40. The Seven Value Stream Mapping Tools (Hines and Rich, 1997)

	Mapping tool						
Wastes/structure	Process activity mapping	Supply chain response matrix	Production variety funnel	Quality filter mapping	Demand amplification mapping	Decision point analysis	Physical structure (a) volume (b) value
Overproduction	L	M		L	M	M	
Waiting	H	H	L		M	M	
Transport	H						L
Inappropriate processing	H		M	L		L	
Unnecessary inventory	M	H	M		H	M	L
Unnecessary motion	H	L					
Defects	L			H			
Overall structure	L	L	M	L	H	M	H

Notes: H = High correlation and usefulness
M = Medium correlation and usefulness
L = Low correlation and usefulness

Hines and Rich (1997) discussed problems related to existing tools for conducting value streams. The seven tools are used to eliminate potential waste and provide a comprehensive view of the value stream in a new and improved configuration. The first tool, Process Activity Mapping, focuses on creating solutions to eliminate waste. The second tool, Supply Chain Response Matrix, identifies activities constraining the process so that these activities can be targeted for elimination or improvement. The third tool, Production Variety Funnel, helps the team understand how products or services are produced. The fourth tool, Quality Filter Mapping, identifies problems related to quality. The fifth tool, Demand Amplification Mapping, shows changes along a supply chain and identifies a decision support system. The sixth tool, Decision Point Analysis, helps identify "the point in the supply chain where actual demand-pull informs forecast-driven push" (Hines and Rich, 1997). The seventh tool, Physical Structure, helps develop a holistic view of the supply chain, for example, understanding how the industry operates and where it might be improved. Using the Value Stream Mapping Analysis Tools (VALSAT) approach is an effective method for selecting the best tool at different steps.

3.2 Value Stream Mapping in Construction

Based on the literature search, the application of VSM in construction is divided into three themes: construction process, macro-process, and construction support process.

3.2.1 Construction Process

There are a lot of issues existed in the construction process, like: consumption of unnecessary resources generates significant waste, environmental problem, and high customer dissatisfaction, etc. However, research indicates that the construction industry currently focuses on the design and operation stages of projects rather than on the construction process.

Four studies have discussed how to use VSM to improve the construction process. Pasqualini and Zawislak (2005) applied the VSM to define a product family. In the construction process, structural elements like walls, slabs, and columns are the main product family analyzed. Unlike a product in manufacturing, where the amount of inventory can be simply counted, the units on a construction site are diffuse and the units flowing through the value stream are different. This study selected the masonry stage to be analyzed. For the current state map, the time of production in construction is too long to collect in a single day. Therefore, the average time of a stage is used. In the analysis of the current state map, based on a schedule developed from the contract, the Takt Time can be calculated, which is the effectively available worked time multiplied by the amount of area worked. As a result, takt of construction will indicate the time in which an area should be worked, or the rhythm of production according to the contract stating the customer's demand. Based on an analysis of the current state map, a future state map can be drawn in the same way as in a manufacturing context.

In similar case studies conducted by Rosenbaum, Toledo, & Gonzalez (2014) and Fontanini et al. (2013), the masonry stage was also selected as the product family analyzed for understanding VSM in construction.

VSM application in construction is hindered by the following identified factors:

(1) A hidden essential for effective VSM is the repetition of the production process. However, every construction project is unique.
(2) VSM is a quantitative tool that uses a list of process data to portray the current state of the process and to figure out the future state. However, most construction companies do not fully track construction processes and collect data.
(3) Key concepts/elements used in VSM, such as inventory, cycle time, Takt Time and change-over time, are defined in the manu facturing context; this differs from the construction context (Yu, Tweed, Al-Hussein, & Nasseri, 2009).

Therefore, modifications of VSM are necessary, due to the differences between manufacturing and construction (Pasqualini & Zawislak 2005). Pasqualini & Zawislak (2005) utilized a modified Value Stream Mapping and made some adjustments at each stage to enhance the production process in a Brazilian construction company. Yu et al (2009) used the modified VSM to reduce waste in housing construction. In this study, the products of production home building can be seen as a single product family, because they are constructed following similar processing steps and sharing the same sub-contractors. On a construction site, houses do not move along a production line; however, workers move from one house to another. Thus, the operations performed by a trade crew can be viewed as a continuous flow. In this case, one house production process was divided into five stages after considering the size of the value stream map, logical relationships and the total duration of the construction activities. These five stages are the foundation, lock-up, interior and siding, pre-finals and finals. After identifying the target stage to be improved, which is the foundation stage in this case, a current state map can be drawn. Figure 1 shows the current state map:

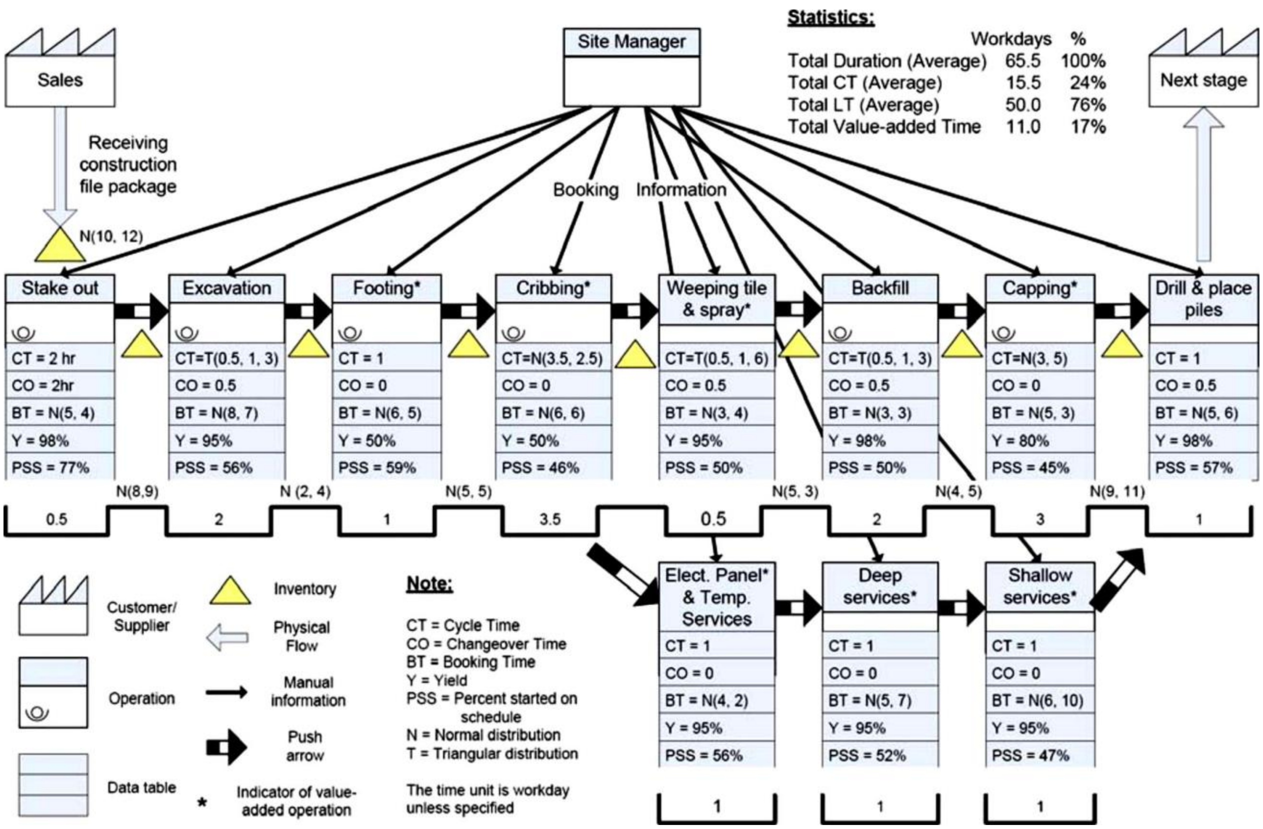


Figure 1. Current -State Map of Home Building Process (stage 1), Reprinted from Yu et al (2009)

The future state map can be developed after an analysis of the current state map, during which waste is identified. The focus of the future state map is to eliminate the cause of waste and improve the value stream into a smooth flow. Four measures are used in future state mapping. They are establishing a production flow and synchronizing it to Takt Time; leveling production at the pacemaker task; restructuring work and improving operational reliability with work standardization, and total quality management for this study. Figure 2 shows the future state map:

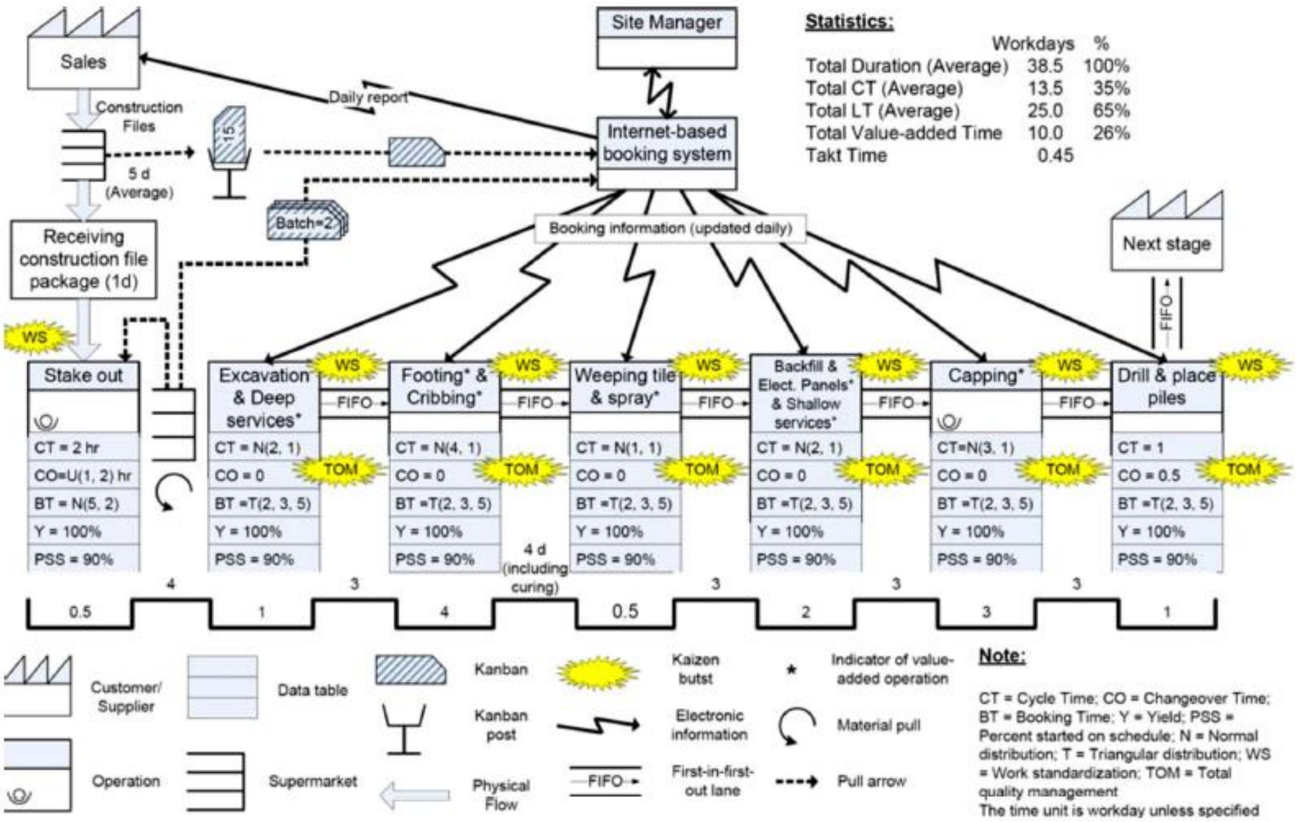


Figure 2. Future-State Map of Home Building Process (stage 1), Reprinted from Yu et al (2009)

These cases demonstrate that VSM is a tool used to identify the sources of production waste, quantify them, and suggest reduction strategies during the construction process.

3.2.2 Macro-process

Another principle issue for the construction industry consists of the competition for projects that are mainly cost centered: the cheapest bid wins and an extremely traditionalist industry contributes little time, money or vitality in advance, thus acknowledging only incremental changes.

Due to this problem, Matt, Krause, and Rauch (2013) presented an agreeable and interdisciplinary research project, “build4future,” that plans to create and implement a cooperative project platform for an industrialized, coordinated construction project. The fundamental target of "build4future"is to reconsider and update the entire value chain for customized construction, including a discrete number of diverse players, and to achieve a level of productivity and industrialization known in different industries. The author utilized a case study of a client scenario of medium-value wooden houses to show its application. In the first step, the author grouped the client scenario as "middle-class wooden house." The second step is to model lean-optimized procedure patterns, which are computed taking into account the weighted necessities for the client scenario. Four utilitarian bunches of procedure patterns, which demonstrated that the most noteworthy estimation of advantages must be decided to design the value stream, appeared in the following: request satisfaction, hierarchical, project control, procurement logistics. This case demonstrated how to design an integrated and customized value stream map for the construction industry.

Another study conducted by Mastroianni and Abdelhamid (2003) demonstrated the application of value stream mapping in project delivery. Owners of projects are expanding their desires about how a project is conveyed and its final result. A capital project at Walbridge Aldinger was tested by the client (Ford Motor Company) to use lean manufacturing ideas for the construction. In the study, WA applied VSM to interior issues to test its viability for enhancing processes. The outcome was both time and cost savings.

3.2.3 Construction Support Process

In this paper, construction support process focuses on the construction supply chain. Construction is a fragmented industry, with risks shared among owners, designers and contractors, suppliers, and vendors. This fragmentation results in higher coordination requirements in the autonomous supply chain during construction, when compared with other industries. Identifying and eliminating hidden waste is the main objective for those intending to enhance system performance because scholars have demonstrated that waste is ubiquitous in construction supply chains (Luhtala, Kilpinen, & Anttila, 1994; Vrijhoef & Koskela, 2000). The accompanying research demonstrates VSM utilization in the construction supply chain.

Womack and Jones (2002) extended VSM to Value Stream Macro Mapping (VSMM) to delineate an entire supply chain, involving several companies. Then Fontanini and Picchi (2004) introduced an exploratory case study of the utilization of VSMM on the aluminum supply chain, from crude materials to the job site installation of aluminum components. This tool was applied to distinguish waste among several actors in the aluminum components supply chain, such as designers, contractors, aluminum windows manufacturers and aluminum manufacturers.

Alves et al (2005) examined the utilization of VSM for make-to-order products in the fabrication of Heating Ventilating and Air Conditioning (HVAC) sheet metal ductwork. The authors explore, understand and depict job shops as dynamic systems. In this environment, Takt Times, batch, and buffer sizes must be constantly updated to reflect changes in the system. The VSM for a job shop must be adaptable to manage the dynamic functioning of job shops, e.g., maps may change day to day, as indicated by the products planned for manufacture. To manage successive changes on approaching requests from project sites, different parts of the production system for sheet metal ducts that ought to be caught in the maps incorporate the accessibility of a diverse workforce for shop and site work; a single stream of product and worker; and improvement of estimates and limited portions. However, the system investigated does not systematically keep track of the data needed to develop lean future state maps. Some critical reference markers like Takt Time, execution measurements, EPE, and batch sizes cannot be figured because of the absence of data about the system examined. The trouble in setting these numbers hampers the execution of lean concepts and tactics to streamline production flow in a job shop.

DISCUSSION

After analyzing current papers, the application of VSM in the construction industry could be grouped into three categories:

(1) Construction process: VSM identified wastes in environmental and production performance; modified VSM identified waste during a stage of the construction process;
(2) Macro-process: used an integrated and customized VSM to eliminate waste; used VSM as a lean tool to reduce waste and add value in the project delivery to satisfy customers;
(3) Construction Support Process: used VSM to re-engineer the production process; VSMM may improve the supply chain; application of VSM on job shop.

Although several papers address using VSM as a lean tool to identify waste and add value during the construction process, the nature of production is different when compared with manufacturing. What's more, due to the dependence and variation of construction supply chains, only limited studies of the application of VSM to the construction supply chain are presented. Unlike manufacturing, a construction project is unique, with no repetition of the production process, barely tracking construction processes and data, and highly variable. VSM has potential but cannot be used directly in construction. In order to use VSM during the construction process, some adaptations are necessary, in each stage, such as change of concepts and product family, etc. New methods have enhanced the utilization of VSM in construction, for example, some studies have demonstrated that a modified VSM could improve the production process in construction. As currently understood, VSM must be re-thought and re-designed if it is to be used as a lean tool in the construction industry.

CONCLUSION

Based on the structured literature review of current research relevant to VSM in construction, VSM utilization in construction is grouped into three process categories: construction process, macro process, and the construction support process. Because the nature of the product is different, VSM is a quantitative tool that uses data to depict the current state map, and key concepts/elements are defined in the manufacturing context, an adaptation of VSM is necessary.

This study used a Structured Literature Review to develop a better understanding of VSM and how it is currently employed in the construction industry to recommend what needs to be done in future research. From the literature, a better understanding is achieved of the obstacles that impede the application of VSM in construction.

Future research could focus on how to apply a modified VSM and combine with other tactics of the lean methodology to improve the effect of applying VSM in the construction industry.

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