# CONTRUCTION SITES: USING LEAN PRINCIPLES TO SEEK BROADER IMPLEMENTATIONS

**Flávio Augusto Picchi[1], Ariovaldo Denis Granja[2]**

## ABSTRACT

This paper aims to evaluate Lean Thinking applications possibilities concerned with the construction job site flows, by identifying the potential of using lean principles to structure implementations, seeking broader results.

From one hand, previous studies indicate that it is feasible to use lean tools and techniques in construction sites. On the other, poor implementations of lean concepts are often observed when tools are implemented in isolation, without a full lean system perspective. In a manufacturing environment, mapping the value stream is an essential step in creating a lean endeavor, generally followed by the implementation of flow and pull tools.

The authors argue that using the five lean principles is a step in the right direction also on construction sites, enabling the discussion of Lean Thinking applications from a rather fragmented and isolated view to a strategic point of view. Finally, the authors suggest actions for implementing available lean tools as part of a broader perspective, based on lean principles.

## KEY WORDS

Lean Thinking, lean construction, construction management, construction site, flow and pull.

1 Associate Professor, Architecture and Construction Department, School of Civil Engineering, Architecture and Urban Design. Av. Albert Einstein, 951, Caixa Postal 6021, Univ. of Campinas, Campinas/SP, Brazil, CEP 13084-971, Phone +55 19/3788-2082, FAX 19/3788-2411, adgranja@fec.unicamp.br.

2 Director, Lean Institute Brazil, Rua Topázio 911, São Paulo/SP, Brazil, CEP 04105-063, Phone +55 11/5571-6887, FAX 11/5571-0804, fpicchi@lean.org.br

## INTRODUCTION

The concept of Lean Thinking has its roots on Toyota's Production System (TPS), specifically in the automotive industry. Womack *et al.* (1991) first introduced this concept by establishing a new paradigm for production in a manufacturing environment. Lean Thinking relies heavily on eliminating waste, understood as any human activity that absorbs resources but creates no value (Womack and Jones 1996).

Construction differs in many ways from manufacturing. Koskela's pioneer work (Koskela 1992) was the first attempt to seek understanding of Lean Thinking on the construction sector. Since then, several researches have been performed (e.g. Howell and Koskela 2000, Howell 1999, Ballard and Howell 1998) aiming to establish a conceptual understanding as well as to devise successful practical applications in the context of construction.

The present research consists mainly of a literature review. By using this exploratory methodology, the authors aim the development of a systems synthesis and a conceptual framework. The authors employed an inductive approach from existing works in this field, seeking a wider conceptual synthesis. This framework is based on the five lean principles stated by Womack and Jones (1996): value, value stream, flow, pull and perfection. In this study the approach is limited to the job site flows. This discussion is part of a broader framework of crossing the five lean principles and the five construction flows, namely, business, design, supply, job site and use and maintenance flows (Picchi 2001)

While several cases of Lean Thinking applications in construction have been discussed, most of them focus on isolated tools and techniques (Santos 1999). This kind of application is considered a major reason for poor implementation of lean concepts, consequently yielding few meaningful results (Rother 1997). Lean Thinking successful implementation demands for a correct perception of philosophy, systems and techniques involved (Shook 1997).

The main goal of this research is to appraise examples of Lean Thinking applications possibilities restricted to the job site flow, by figuring out potentials of taking lean principles to structure implementations, focusing on broader results. The analysis aims to provide a wider and integrated understanding of lean concepts and techniques that may be applied to construction sites, and to determine present gaps and future research priorities as well.

## LEAN TOOLS IMPLEMENTATIONS AND THE FIVE LEAN PRINCIPLES

There are several reports on implementing lean tools in the job site flow. In the following sections, the authors present and discuss some related works on this issue in the context of the five lean principles. The authors do not aim to show a complete survey of all the works related to this issue, but rather to refer to selected examples of how lean tools have been employed.

### VALUE

The correct definition of how value is perceived from the client's point of view is the starting point to the application of Lean Thinking. Focusing on the whole enterprise, this perception includes the determination of the main characteristics of the product and the associated benefits the client is willing to pay for. This is the first step to waste recognition, defined as everything that adds no value from the clients' perspective (Womack and Jones 1996). As this work focus exclusively on the job site flow, its particular consideration is affected in a certain way.

One possible explanation for these specifics could be identifying on the job site processes, what is perceived as value from the client's point of view. One can point out that traditional construction process improvements are related to this principle. However it is important to observe that these improvements are generally conceived having in mind cost reduction, what is an important part of value, but not always considering possibilities of enhancing features that are perceived as value by the client's eyes.

### VALUE STREAM

Managing physical flows of people, materials and equipment in construction sites must be taken as part of the production planning and control process (Alves and Formoso 2000). In another related work, Elfving *et al.* (2002) have examined the reduction of lead times for specific components, such as electrical switchgear. Results pointed out that long lead times have are caused by the large number of design iterations and change orders.

Ballard *et al.* (2002) and Ballard and Howell (2003) used a process map flow to analyze precast concrete fabrication. That approach was useful to identify opportunities of using flow and pull lean techniques. Results report improvements up to 181% in the productivity rate. In another work, Walsh *et al.* (2003) identified opportunities of reducing 30% the cycle time in high volume home building, analyzing a extended process map of trades.

The Lean Thinking analogue tool for depicting production processes is the value stream mapping (Rother and Shook 2000). By adopting this approach, process understanding can be improved and conditions for reducing variability and waste are achieved.

Mapping the value stream of ready-mix concrete regarding batching and delivery has been carried out by Tommelein and Li (1999) Results showed that the current practices for managing the concrete supply chain upstream could be improved toward a just-in-time (JIT) lean approach. Structural steel supply flow in industrial and building construction has been analyzed by Tommelein and Weissemberger (1999) Again by using value stream mapping lean tool, results pointed out to the use of buffers at nearly all stages in the process, hindering the steel to flow properly. These evidences show that remarkable process improvements may be achieved by implementing lean concepts in a broader scope.

### FLOW

The concept of flow is one of the core elements of Lean Thinking philosophy to achieve complete removal of waste. It is related to the ideal of flowing value without interruptions, eliminating waste and reducing the lead time of generating new products or services (Womack and Jones 1996). Practical implementations are geared towards production cells for instance, where remarkable productivity gains can be achieved. Concepts applied in this context are: one piece flow, multi-functional operators, and controlled and standardized rhythm (Rother and Harris 2002).

Creating continuous flow in construction sites is a huge challenge due to its fragmented nature, low standardization patterns of activities, one of a kind features of construction's products, etc. (Koskela 2000). Randolph Thomas *et al.* (2003) carried out a work flow study on three bridges construction sites. Results showed 12.063 hours of labor resources employed on the three bridges, and from these 4.601 hours (38%) were related to reworking, batch and queues, and other inefficiencies. The Last Planner system of production control (Ballard 1997, Ballard 1999b, Ballard 2000) seeks to quantify work flow reliability by the PPC (percentage of planned assignments completed). According to Ballard (1999b), PPC has been measured at levels ranging below 30% to 60%, with rare exceptions above those levels. Raising PPC at levels above 90% seems to require some additional actions as pointed out in that work.

Santos 1999; Santos *et al.*1999; Santos *et al.* (2000) and Santos and Powell (2001) identified the use of some tools to support flow in six job sites. The authors pointed out that implementations of reducing work in progress and downsizing batches in construction sites, important elements for creating continuous flow, are still unusual.

One of the cornerstones for achieving continuous flow on manufacture is the working cell (Suzaki 1987); however, initiatives of implementing this concept in construction are still rare. Working cells in construction job sites have been addressed in a pioneer case study focusing on drywall technique (Santos *et al.* 2002). Results showed that visual controls in the workstation, packages and in the employed materials are key features for achieving meaningful implementations of working cells in construction. Howell *et al.* (1993) and Ballard and Tommelein (1999) have undertaken studies about the interaction between diverse work cycles concerning different teams. Results showed that unbalanced activities between construction trades are a important reasons for difficulties on stabilizing flow. Connected to this issue, repetitive and standardized work cycles in home buildings have been investigated by Ballard (2001).

Flow depends heavily on the quality management of activities being carried out. Avoiding reworking related to quality deficiencies is essential for assuring products to flow properly. Research work on reducing variability by using *poka-yoke* (mistake-proof) devices has been undertaken by Santos and Powell (1999). According to this work, *poka-yoke* devices could be installed on construction machinery supplied on site avoiding incorrect use of these kinds of products. In spite of that, little use of these mistake-proof devices has been noticed in construction sites, mostly of them related to safety management.

The use of visual control devices for implementing the concept of transparency is used in the lean system for immediate problem detection and to improve flow reliability. Santos *et al.* (1998); and Formoso and Santos (2002) studied some examples of visual controls in job sites observing a tendency of straight correlation between transparency and efficiency in these cases. In a similar way, Heineck *et al.* (2002) reported productivity gains in construction sites, by implementing improvements on process transparency. Moser and Santos (2003) depict the use of visual controls as imperative for implementing working cells in the construction sector.

Standardized work is another fundamental aspect for stabilizing flow (Rother and Harris 2002). At the same time, Santos *et al.* (2002) showed the paradox of construction companies developing written standards but at the same time failing to implement and maintaining standard practices. Results pointed out for an urgent need for a more widespread promotion of visual management approaches within the construction management. Work structuring is regarded by some authors as revisiting construction processes for waste reduction, and it can be considered as part of the requirements for achieving improvements on flow consistency (Ballard 1999a; Tsao *et al.* 2000, Tsao and Tommelein 2002, and Ballard *et al.* 2001).

### PULL

Pull and flow lean principles are regarded as the core characteristics of Lean Thinking, and are cornerstones for the elimination of waste. A lean pull technique was successful reported in a pipe-spool construction process (Tommelein 1998). By using this technique, real-time feedback from the job site can be used to drive fabricator's off-site work, and vice versa. Benefits reported are smaller buffers, earlier project completion and increased productivity, when properly implemented. In a similar work, steel supply chain for industrial and residential buildings has been analyzed having in mind the pull production concept (Tommelein and Weissenberger 1999).

Just-in-time production (JIT) is also encouraged to construction application by implementing better managing practices for uncertainty elimination and causes of flow variation (Ballard and Howell 1995; Ballard 1998). More on implementing JIT logistics to the supply flow of building materials on site has been carried out by Bertelsen and Nielsen (1997).

### PERFECTION

One may note a continuous progress in the adoption of quality systems programs in the construction industry. Results of this strategy are that reasonable improvements and standardization of tasks have been achieved. Lean Thinking adopts a quite broader concept of standardized work, which stabilizes processes by defining precisely: sequence, rhythm, and allowed inventory (LEI, 2003).

It is important to note that Lean Thinking focus on continuous learning and improvements directly on the base of the functional hierarchy, with a scientific and rotinized method (Spear and Bowen, 1999; Fujimoto, 1999). Adopting this strategy ensures one that problems can be efficient detected and rapidly solved. Therefore, one may point out that even in successful cases of quality programs implementation, additional elements based on lean concepts are necessary, so an environment of continuous improvements and learning is accomplished.

## DISCUSSION

It is possible to infer from the literature (Rother 1997; Santos 1999, Johansen *et al.* 2002), and from the author's observations in the manufacture and in construction sites, that lean implementations are usually very fragmented. These pioneer cases are important steps towards lean dissemination in job sites, but lean tools use based on a broader lean system analysis is necessary for more significant results (Womack and Jones 1996; Liker 1997; Rother and Shook 2000).

Figure 1 summarizes examples of lean tools already used in job sites.

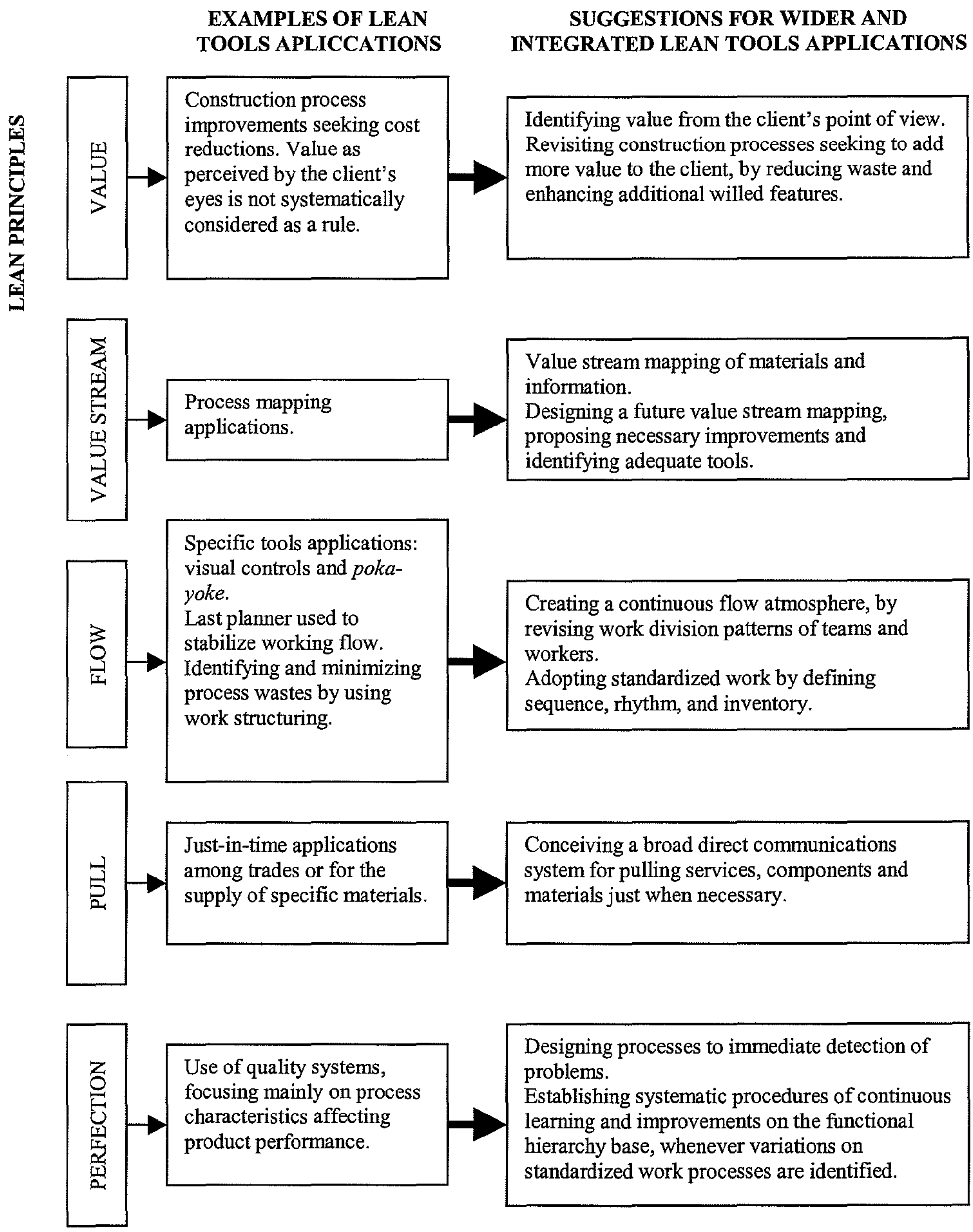



Figure 1: Examples of lean tools already reported in construction implementations and suggestions for wider and integrated applications for the sector.

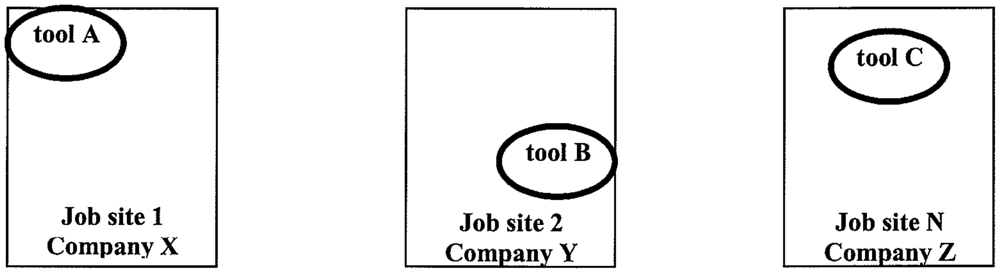
These examples indicate that, although these tools were developed in the different environment of manufacturing, they can be adapted to construction. The authors consider that lean implementations are also viable for the construction sector. Results obtained even in the present fragmented way of lean implementations are positive and encouraging (Ballard and Howell 2003; Santos 1999; Koskela 2000).

In most cases just one tool has been used in each job site, without connection with other tools or lean principles. The understanding of each tool as a means for perceiving a lean principle, as depicted in Figure 1, is a first step for wider applications. Figure 1 also presents suggestion for extensive applications in job site, seeking core aspects implementation for each principle. Based on the literature review and on the authors' experience implementing lean in different industries, we can identify three different lean implementation scenarios, depicted in Figure 2.

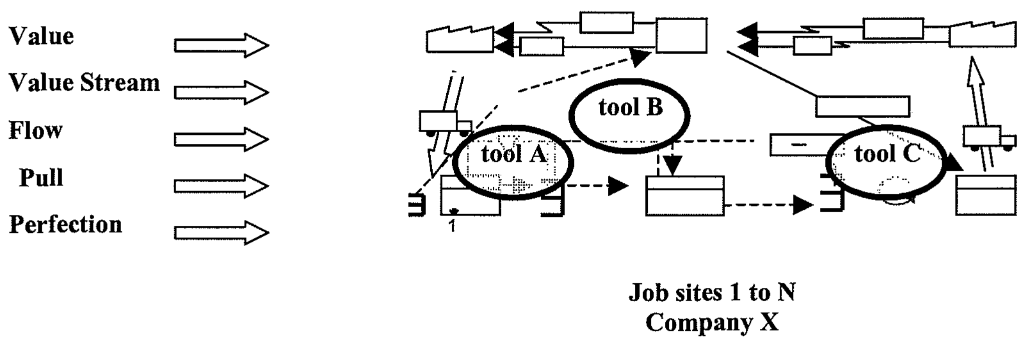
Scenario 1 of Figure 2 shows the most frequent applications pattern observed so far in construction companies. The limited results obtained by this approach have already been discussed.

Scenario 2 represents a major step towards a wider application of lean thinking in job sites: the systematic interpretation of the five lean principles combined with tools use driven by a future state value stream mapping designed to improve flow. Value stream mapping as proposed by Rother and Shook (2000) is a powerful tool to provide a large view of a lean system for each company, avoiding fragmented implementations. This tool can provide a guide for several steps in a lean transformation, as we can conclude comparing, for example, with the six steps proposed by Serpell and Alarcón (1998) for construction improvements. Value stream mapping present state covers the two first steps: diagnostic of current situation and analysis and identification of improvement opportunities. Future state of value stream mapping gives direction for the third and fourth steps: definition and evaluation of improvement strategies and actions and planning of implementation. The process mapping cases referred in the previous section value stream show the potential of this kind of analysis, although the cases so far are applied to partial job sites activities and do not take advantage of the full value stream mapping, combining information and material flow (Rother and Shook 2000).

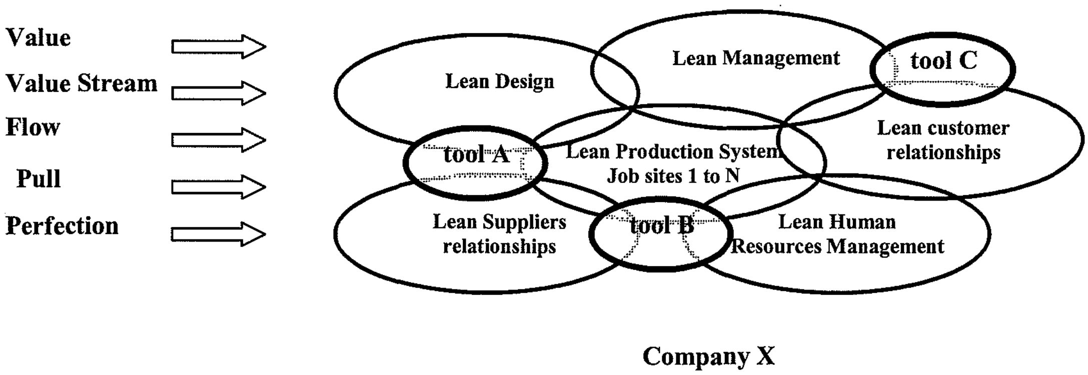
There is no notice of implementations in construction with the amplitude of scenario 2. The construction of this scenario is a challenge for future researches and practical implementations. In fact, researchers and practitioners face a larger challenge, that is, the application of lean to the job site as part of a company-wide transformation. This situation is illustrated in scenario 3 of Figure 2. As an example, Thomassen *et al.* (2003) describe a case of lean application in job site that made clear to the involved agents that job site implementation would not evolve without lean design and lean supply. The necessity of involving several functions of the company, such as product development, suppliers and customers relationships, etc., had already been emphasized by Womack and Jones (1996), but hardly accomplished (Rother 1997). Liker (2004) recognizes 14 management principles that drive the Toyota Production System, named The Toyota Way; these principles are organized in four categories: philosophy, process, people and partners and problem solving.




**Scenario 1 – Fragmented tools application**




**Scenario 2 – Integrated Job site application**




**Scenario 3– Lean Enterprise application**

Figure 2: Different scenarios for lean application

It seems that lean implementations are most effective when considering the construction company as a whole, and should be considered as a long-term goal. Nevertheless, inadequate processes are a recurrent characteristic of construction sites. In this regard, Value Stream mapping is a valuable tool for eliminating waste and promoting value. The authors consider that systematic improvements of processes via Value Stream mapping followed by flow and pull implementations are effective steps for lean implementations. One last point to Figure 2, Scenario 3, is that this integrated lean implementation status depends heavily on the leadership process. Leaderships should be in charge of seeking potential results by implementing lean, and by aligning them with the strategic targets of the company. The experience of the authors shows that lean implementations can be achieved by different ways, for instance, by a process of identification of lean potentials in another company by the leadership and then deciding to apply in his own, or even through specific lean implementations in pilot projects. As a rule, results obtained in the very first steps of lean implementations taught leaderships that wider and integrated applications are the key for even better outcomes.

## CONCLUSIONS

Lean applications in job sites so far are mainly focused on isolated tools implementation, with limited results. These pioneer cases show that the tools can be used in the construction environment. Broader applications and higher level results can be achieved by using the five lean principles as a direction, value stream mapping to draw a future state and identify the adequate tools use, and considering job site implementation as part of a lean enterprise transformation.

The authors have noticed a lack of awareness on the following research issues:

• Using value stream mapping for the understanding of waste generation on construction sites, and correct actions for implementing available tools (Rother and Shook 2000).

• Full understanding of the flow principle applied to processes as a very first priority towards lean (Rother and Shook 2000). An environment of continuous flow should bring meaningful results, by adapting tools as described in Rother and Harris (2002).

• Broadening the understanding of standardized work within construction processes, continuous learning, and systematic improvements (Fujimoto 1999).

• Application of the lean business system to the whole construction company, resulting in more meaningful job site implementations, leading to a higher level of results (Womack and Jones 1996; Liker 2004).

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