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LEAN DESIGN IN BUILDING PROJECTS: GUIDING PRINCIPLES AND EXPLORATORY COLLECTION OF GOOD PRACTICES

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ABSTRACT

In Construction, the application of lean thinking in design development comes as an innovation in the sector by bringing focus on what is waste and what is value.

In this context, the aim of this paper is to, first, identify which are the guiding principles for lean product development, by literature review in different industries; and, second, based on these structured principles, perform an exploratory collection of good practices in building design projects.

In order to identify the guiding principles a literature review was conducted and, after that, case studies were carried out in three Brazilian Construction and Architecture companies, plus one international Architecture company.

The guiding principles showed to be a good structured way of colleting lean design good practices; additionally, in the case studies it was detected if and how lean design principles are applied in the companies.

As a contribution, this work established structured lean product development guiding principles and gathered an exploratory collection of building design good practices.

For future work, the evolution of the guiding principles in a framework for application, the adaptation of some lean principles for building design and more studies to test the application of related practices in the sector are suggested.

KEYWORDS

lean product development, lean design, design management

INTRODUCTION

In Construction, the design development process has great influence on the quality and success of a Project. The application of lean thinking in design development comes as an innovation in the sector by bringing focus on what is waste and what is value.

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Several authors have established structured principles, practices and tools for a generic lean product development, having manufacture as reference, highlighting Womack et. al. (1990), Ward (2007), Morgan & Liker (2006) and Kennedy et. al. (2008).

In building design there are several studies that consider the application of some of these principles (Ballard & Zabelle 2000; Jorgensen, 2006; Reifi & Emmitt, 2013), for example: the use of lean tools and techniques to achieve value delivery, integration and waste reduction in the process. Additionally, Lean design management has been started in some building projects by now bringing good results (Lostuvali et al. 2012, Vinas 2014).

However, most studies in building design focus only on a few lean practices without considering the full application and all lean product development principles described in literature. According to Reifi et. al. (2013), although there are a certain number of studies that approach lean design related themes, it is still under debate in terms of what it is, and how to best implement it.

For this reason, the aim of this paper is to first identify which are the guiding principles for lean product development by literature review in different industries and, second, perform an exploratory collection of good practices based on these structured guiding principles.

It expects to establish a structured way for collecting lean design practices in building projects and, based on that, to present the findings extracted on the exploratory case studies.

METHOD

To identify the lean product development guiding principles, a literature review was conducted considering the main authors that have established principles for lean product development in different industries.

After that, case studies were carried out in three Brazilian Construction and Architecture companies, that do not openly apply lean design (Study I), plus an international Architecture company that declares to use lean design techniques (Study II).

For data collection, design managers and architects from the studied companies were interviewed and provided documents to illustrate the reported practices.

The research phases were: literature review, guiding principles proposition, questionnaire's preparation, case selection and characterization, information gathering, information analysis and conclusions.

LEAN PRODUCT DEVELOPMENT PRINCIPLES

KNOWLEDGE HIERARCHY AND TERMINOLOGY

To organize existing theoretical and practical knowledge, Koskela (1996) proposed a three layers pyramid that follows a hierarchical progression from high abstract to low abstract layers. Santos (1999) broke the third layer called *methodology* and proposed a pyramid including four layers, from top to bottom: concepts, principles, implementation approaches and tools/ techniques.

Based on that, in this paper the terms will adopt the follow definitions:

a) Concepts: abstraction or idealization of a topic (Koskela, 1996);

b) Principles: describe the pathway to transform existing reality through the basic idea set by a concept (Santos, 1999);
c) Practices: describe how to implement a principle;
d) Tools and Techniques: are designed to help the determination of specific answers to specific problems (Santos, 1999);
e) Methods: a combination of practices, tools and techniques that approach the same theme.

LEAN PRODUCT DEVELOPMENT GUIDING PRINCIPLES

Lean thinking was first applied on production process; however, eliminating waste in production is possible until a certain point when product and process engineering becomes a critical barrier (Morgan & Liker 2006).

Ward et al. (1995) presented the Toyota way of developing products and how delaying decisions was their second biggest paradox, followed by their production system. In that time, the authors already believed that innovation on product development would be as important as their revolutionary production system.

In the same way, Sobek et al. (1999) highlighted how Toyota's set-based design contributed with the extraordinary results that the company had in comparison with others.

On the theoretical basis about lean product development, some authors put their efforts on adapting and elaborating lean principles focused on this environment.

Womack et. al. (1990) firstly pointed some lean techniques applied to product development: Leadership, Teamwork, Communication and Simultaneous Development.

Ward (2007) described five main foundations about it: Focus on value; Entrepreneur System Designers (ESDs); Teams of Responsible Experts, Set-based concurrent engineering; Cadence, Pull and Flow.

Kennedy (2003) proposed a methodology for implementing lean product development highlighting the importance of leadership and workforce involvement and, later (Kennedy et. al. 2008), extracted five critical success factors adding cross project knowledge as one of them.

Morgan & Liker (2006) developed thirteen principles separated into three groups: process, skilled people, tools and techniques. These principles compiled practices that must be applied and aligned in order to achieve the results by a lean process.

Recently, Hoppmann et. al. (2011) elected eleven lean product development principles based on the themes addressed by the main authors (Womack et. al. 1990, Morgan & Liker 2006, Ward 2007, Kennedy 2003).

As one of the attempts of this paper, it was established which are the lean product development guiding principles. These principles, showed on Table 1, were based on Hoppmann et al (2011) with the addition of the principle *Focus on Value* and the merge of *Simultaneous Engineering* with *Set Based Design* in a single principle. At this time, structured principles were selected from literature that approach a generic lean product development, bearing in mind that these principles are able to be applied in all industries, including building design.

This principles list supported the information extraction in the case studies and the data organization of this paper.

Table 6 - Lean Product Development guiding principles

Principles	Womack et. al. 1990	Ward 2007	Morgan & Liker 2006	Kennedy et. al. 2008	Hoppmann et. al. 2011
1- Focus on value		X	x		
2- Strong leadership	X	X	x	x	x
3- Specialist Team		X	x	x	x
4- Workload levelling			x		x
5- Responsibility-based planning and control		X	x	x	x
6- Cross-project knowledge transfer			x	x	x
7- Set based design	x	X	x	x	x
8- Supplier integration			x		x
9- Product variety management			x		x
10- Rapid prototyping, simulation and testing					x
11 -Process standardization		X	x	x	x

LEAN DESIGN IN BUILDING PROJECTS

In Construction, the discussion about lean application on product development achieves the design management field of work, for this reason it is called "lean design" when it concerns building projects.

Koskela et al.(1997), Tzortzopoulos & Formoso (1999), Ballard & Zabelle (2000) started the discussion considering the application of some lean practices in building design such as: Last Planner, reducing activities that do not add value, reducing process variability, reducing cycle time, multidisciplinary teams and simultaneous engineering.

More recent studies bring a wider approach. Jorgensen & Emmitt (2009) define that lean design applies a system to generate value and eliminate/reduce waste in building design; adopts customer's voice to define what is value; approaches design management with focus on process and flow; understands design activities through three concepts: change, flow and value generation; manages time pulled by client's needs;

From lean design management literature review, Reifi & Emmitt (2013) highlight four dominant themes related to the reduction of waste and the enhancement of value: briefing and client interaction, value and value stream mapping, lean culture and assembling the team and information flow.

The importance of design briefing was highlighted by other authors as well. According to Reifi et al. (2013) the brief plays a vital role in presenting and communicating client requirements to the design and construction teams. By the fact that lean design processes is still under discussion, design brief can assume an important role in articulating declared and non-declared client's requirements and values and in defining how it must be delivered.

Another theme discussed in literature is how design workshops can contribute to lean design implementation (Thyssen et al. 2008; Emmitt et al. 2004). The workshops can occur several times and have different goals each time contributing to value identification, simultaneous development, team integration and process standardization, becoming an essential technique to add value in design process.

Regarding value adding, Target Value Design (TVD), a technique first developed on industry environment as Target Costing, it is being applied in Construction sector by including cost as a design criterion, seeking waste reduction and value generation. (Ballard 2006; Pennanen et al. 2010; Ballard 2011).

Team integration, earlier supplier involvement and multiple alternatives development are addressed by several authors (Ballard & Zabelle 2000; Jorgensen 2006; Reifi & Emmitt 2013; Emmitt et al. 2004; Thyssen et al. 2008; Ballard 2011) and define a key point for lean design: Set-based concurrent engineering (Womack et al., 1990; Morgan & Liker, 2006, Ward, 2007).

For achieving a lean design process, Integrated Project Delivery (IPD) as a delivery method may be crucial. IPD is when the owner has elected to sign a multi-party contract with the prime designer, contractor and/or other key members of the project team (AIA, 2010). The adoption of this method is currently been pushed by waste and lack of productivity, technological evolution (software) and owner demand for value which are all lean concepts, thus, it is a method that promotes collaboration and integration between members aiming to deliver product with higher value adding.

Moreover, technology also can support the application of lean concepts since there is a huge synergy between BIM technology and lean, once the use of BIM can enhance model checking and simulation methods enabling the purchaser to compare offers and construction alternatives (Breit et. al. 2010; Sacks et. al 2009)

Lean design management has been started in some building projects by now. In Cathedral Hill Hospital, Lostuvali et al. (2012) compared and contrasted their lean initiatives with the principles proposed by Morgan & Liker and conclude that most principles have been implemented to some extent, and a few still need to be worked on.

In the same way, Vinas (2014) described some exceptional results that a lean design development brought in Akron´s Children´s Hospital project including area reduction with higher flexibility in rooms.

EXPLORATORY COLLECTION OF GOOD PRACTICES

After proposing the guiding principles list described previously, two case studies were carried out based on this list for practices collection.

All studied companies deal with projects that have a certain grade of complexity based on its size, technical requirements and management issues. Since lean product development emerged in a complex environment (automotive industry), it is believed that its application in complex projects might bring more relevant results than in simple ones.

CASE STUDY I – CURRENT PRACTICES IN THREE BRAZILIAN COMPANIES

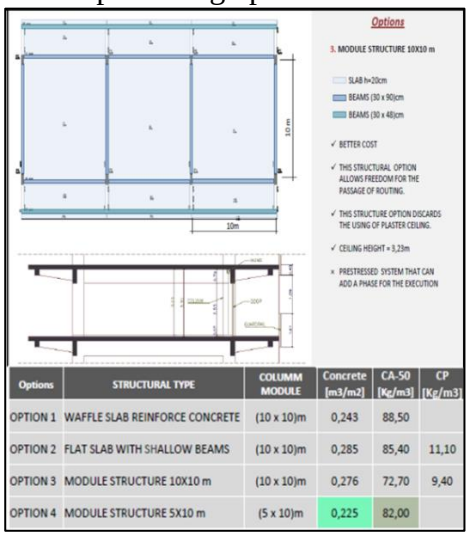
Case study I was carried out in three Brazilian companies: a Construction Company and two Architecture Companies. These companies act in national projects and do not openly

apply lean design techniques; however, possibly there are already some practices aligned to lean design principles.

To exemplify the mentioned practices, interviewed professionals provided documents about two main Projects: Project B, a 100.000 sqm shopping mall; and Project C, a 38.000 sqm Institutional Building. Furthermore, they provided information about corporative processes as well.

The reported practices are detailed in Table 2, from them, the following aspects could be highlighted:

- Value Engineering studies to evaluate systems and design alternatives (Figure 5), which is a tool that is closely connected with TVD and also can support set based design;
- A collection of design indicators that keeps in the company the acquired knowledge in the projects, making easier alternative analysis and design decisions;
- Use of BIM technology for design coordination, planning and quantities' extraction (Figure 6) promoting design simulation and testing prior to construction in order to anticipate design problems and inconsistences.



Options	STRUCTURAL TYPE	COLUMM MODULE	Concrete [m3/m2]	CA-50 [Kg/m3]	CP [Kg/m3]
OPTION 1	WAFFLE SLAB REINFORCE CONCRETE	(10 x 10)m	0,243	88,50	
OPTION 2	FLAT SLAB WITH SHALLOW BEAMS	(10 x 10)m	0,285	85,40	11,10
OPTION 3	MODULE STRUCTURE 10X10 m	(10 x 10)m	0,276	72,70	9,40
OPTION 4	MODULE STRUCTURE 5X10 m	(5 x 10)m	0,225	82,00	

Figure 5: VE study (Case Study I)

Figure 6: BIM coordination model x Site picture (Case Study I)

CASE STUDY II – LEAN DESIGN PRACTITIONER COMPANY

Case study II has been carried out in an international Architecture Company that declares to practice lean design techniques in their projects and it has been an important source of lean practices, tools and techniques. This company acts worldwide having offices in eight different countries and provides architecture services for several kinds of buildings.

The interviewed professional provided some documents to exemplify their lean practices and describe some of them during the interview. The reported lean practices are detailed in Table 2; the following aspects could be highlighted from them:

- *Gemba* walk to understand client's operation and by that improve the requirement and value identification;
- Technical specialist teams to support design. The interviewed described that in Hospital projects they have a group of doctors and nurses for design review, practice that inputs in design the user's needs and functional improvement ;
- Pull planning workshops based on client's milestones to define delivery dates and deliverables. This practice is fully aligned with lean responsibility based planning and control for aligning the project information and for having the project team seeking the same goals;
- IPD as a delivery method including specific metric goals in contractual clauses for designers, TVD studies, supplier and constructor integration;
- The use of mock-ups, built in cheap materials, to test day-by-day procedures and design alternatives. The interviewed exemplified this practice describing a full nursery department of a Hospital project that was built in full scale for doctor, nurses, users, patients and designers to test it.

GOOD PRACTICES FOR LEAN DESIGN IMPLEMENTATION

Based on the results from the case studies, the good practices were organized on Table 2.

Table 7 – Good practices found in the Case Studies

Principle	Good practices	Tools and techniques
1- Focus on value	• Identify value and client requirements (I) (II) • Establish metrics (II) • Establish a target cost (II)	• Cost spreadsheets that distributes a global cost into a ABC analysis to develop a target for each system design (I) • VE studies (I) (II) • Metric goals in contracts. (II) • *Gemba* walk. (II) • Design workshops. (II) • Detailed briefing.(II)
2- Strong leadership	• Select a leader to merge client needs into the design process (II)	

Table 2 – Good practices found in the Case Studies (cont.)

Principle	Good practices	Tools and techniques

3- Specialist Team	• Work with specialists on briefing definition (I) • Form multidisciplinary teams to contribute in technical discussions (I) • Form a team of customers to review the design and operation of the building (II)	
4- Workload levelling	• Develop professionals that have flexibility to work in different types of projects and departments. (I) • Share human resources with other company units and departments (II)	• Software to accurate the spent hours in a Project. (I) • Technology for remote working. (II)
5- Responsibility-based planning and control	• Planning pulled by client's demands (I) (II)	• Pull planning workshops (II)
6- Cross-project knowledge transfer	• Keep design indicators (I) • Promote lessons learned events (I) • Have a design database (II)	• Indicator's spreadsheet (I) • Design search tool (II)
7- Set based design	• Seek the early involvement of consultants, suppliers and builders (I) (II) • Develop more than one design option for client's appreciation. (II)	
8- Supplier integration	• Challenge suppliers on developing solutions to achieve a target cost (I) • Promote design-build and IPD contracts (II)	
9- Product variety management	(No practices were found aligned to this principle)	
10- Rapid prototyping, simulation and testing	• Use BIM technology for planning simulation, coordination and quantities extraction (I) • Build mockups to help the design development process (II) • Simulate design through software to test the design functionality (II) • Test mockups with day by day procedures (II)	• BIM software (I) • Rapid prototyping (II) • Mockups (II) • Simulation software (II)
11 -Process standardization	(No practices were found aligned to this principle)	

Source: (I) Case Study I/ (II) Case Study II

CONCLUSIONS

The guiding principles enabled a good structured way of colleting lean design good practices, making easier the analysis and showing to be a good tool for data collection in future works.

The exploratory studies showed that some principles are being applied in the studied companies, however, low relevant or none practices were found about principles 2, 9 and 11. Moreover, the case studies brought a collection of good practices that detailed ways for applying some lean product development principles in building projects.

As a contribution, this work established structured lean product development guiding principles and gathered a collection of building design good practices detected in three Brazilian companies and one international company.

For future work, an evolution of the guiding principles in a framework for application, an adaptation of some lean principles for building design and more studies to test the application of related practices in the sector are suggested.

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