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Lean as an Integrator of Modular Construction

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ABSTRACT
The use of Lean concepts is growing in several industrial sectors. Corporations are seeking new ways to achieve improved operational performance and to identify process improvement measures to improve workflows. The research presented in this proposes to achieve a conceptual framework that can be used in the modular construction market. The research method selected is Design Science Research (DSR), since the research proposes to create a new artifact constituting the integration of Lean Manufacturing, Lean Thinking, Lean Construction and Lean Office in a consistent manner and one that can accommodate Integrated Project Delivery (IPD). In this paper, Permanent Modular Construction (PMC) will be investigated as an industrial construction process. PMC consists of the manufacture of components of the building with volumetric geometry, produced outside the construction site in a factory environment and then transported to the worksite to be assembled with a set of other modules, with comparably few construction activities carried out on site. In order to execute projects using this construction method it is necessary to integrated design, factory operations, transportation and construction site operations, accounting for different locations and different characteristics in a single workflow: this is one of the primary challenges of PMC.

KEYWORDS
Permanent Modular Construction; Integrated Project Delivery (IPD); Lean concepts

INTRODUCTION
Historically the construction process been characterized by handmade production, but there has been a worldwide shift toward an industrialized approach. This paper presents the use of lean concepts management as an integrating link for Permanent Modular Construction (PMC).
Construction enterprises are seeking new ways to achieve improved performance in their activities and many of the problems identified have been with respect to organizational aspects and workflows (Sacks et al, 2017). The use of Lean concepts can address this gap and bring better results including less project duration to offsite construction (Polat and Ballard, 2006).
This research proposes to create a new artifact which is a conceptual framework integrating the workflow of PMC, Lean Manufacturing, Lean Thinking, Lean Construction and Lean Office in a consistent manner that supports Integrated Project Delivery (IPD), this group of related concepts is called Lean Project Delivery for PMC.

To obtain better results, the construction market should shift manual on site activities to a controlled factory environment (Goulding and Arif, 2013). Offsite construction refers to a construction method that "brings on-site construction works into a climate-controlled facility where advanced machinery and manufacturing technologies can be utilized to prefabricate buildings in a standardized and efficient manner" (Liu, et al, 2017).
The process involves the design and manufacture of units or modules, usually away from the working site and their installation to form the permanent building on the construction site. In its broadest sense, off-site manufacturing requires a project strategy that changes the design process perspective from construction until manufacturing and installation.
PMC as a subset of off-site construction involves prefabrication of volumetric components that are put together to form a complete structure. The units are manufactured in volumetric format, containing structural frame, floor, walls, ceiling and often plumbing and electrical installations (Gibb, 1999). These components arrive on site largely complete, leaving only a small amount of work to be done on site. Examples of PMC buildings include hospitals, mid-sized offices, hotels, and autonomous retail units (Smith, 2015).

LEAN CONCEPTS AND IPD

Lean Concepts

The purpose behind industrializing civil and building construction is to raise construction activities to a better condition in terms of productivity management and quality. The Lean Production philosophy provides a transformative means to accomplish this.
Lean Production has all aspects originating in the automotive industry and specifically the Toyota Production System, but it quickly migrated to other industrial environments (Womack and Jones, 2003). Several industrial sectors have subsequently identified advantages of this novel approach to managing a business, and this has led to the emergence of Lean Thinking (Liker, 2005), which seeks to eliminate waste in productive processes and in the delivery of value through these processes, based on five foundational principles.
The administrative and design sectors also adopted new management techniques with respect to the organization and management of documents, legal aspects, human resource management, and work distribution. By adopting measures to systematize and distribute tasks, offices have adjusted to this new way of managing a company, with a differential that information and physical flows are often difficult to identify, A Lean Office emerges as a philosophy management that seeks quality and efficiency in office activities (Greef, et al. 2012).
In the early 1990´s, Lean Construction emerged which as the evolution of Lean Manufacturing in the construction sector (Koskela, 1992). Considering that the construction environment is quite different from the traditional manufacturing environment, adaptations were required in order for this management philosophy to be applied. Initially, there were 11 guiding principles for the application in construction sites that reflected lean characteristics including reduction of production time, elimination of waste, increase of value for the customer, quality improvement, among other aspects common to all different Lean models applied to different industrial sectors.

Integrated Project Delivery (IPD)

IPD according to the AIA (2014) is a method of delivering projects that seeks to integrate people, systems, business structures, and practical processes through the collaborative use of the

capacity of all participants to reduce waste and improve efficiency through all project phases. IPD includes the following basic features:

- Continuous involvement of the owner and the main designers and contractors from the initial project to the completion of the building;
- Alignment of commercial interests through shared risk/reward, including financial gain at risk, for being dependent on project results;
- Shared control of projects along with the owner, main designers, and contractors;
- Execution of a multi-party agreement;
- Limited liability between the owner and the main designers and contractors.

In construction there are different degrees of collaboration. Owners, to a greater extent than any other interested party, establish the degree of collaboration from the outset of the project through the procurement and hiring process. In this way, owners can establish the baseline for the level of integration they can expect in each project (NASFA et al, 2010). As an important element of IPD it has adopted features developed by Fischer et al. (2017) on a consistent and concise formula to accommodate the IPD elements. Figure 1 represents "The Magic Formula" for IPD developed by Fisher et al. (2017).

Value Definition	***Framework***	***Environment***	***Interactions***	***Network of knowledge***
Enterprise Needs & Constraints	Relational Contract	Right People	Quantity	Conections across bourdaries
Stakeholders Values	Delivery to target cost	Virtual world	Quality	Clarity of customer supplier relationships
Performance Goals	Integrated Organization	Proximity		
Objective & Metrics	Information Infrastructure	Transparency		

Figure 1. The "Magic Formula" for IPD (Fischer et al. 2017)

Close collaboration is the fundamental principle of IPD. All projects participants are motivated to remain focused on optimizing the entire project as opposed to seeking the self-interest of their respective organizations at the expense of other parties involved in the project, as the contracting incentives and contractual rules reward cooperation and encourage innovation (Forbes and Ahmed, 2011).

Moreover the need for a IT solutions that support collaboration has been the driver behind the growth of online collaborative construction technologies. Building Information Modeling (BIM). For instance, uses 3D digital building models containing parametric information to enable integration through enhanced visualization, and ease of data sharing and reuse by various members of the project team. (Yin et al. 2019; Marco and Karzouna, 2018).

The increased collaboration supported by this technology has the potential to reward all participating parties. Although strictly speaking IPD is an approach to contractual agreements among the parties in a construction project, it seeks to drive new ways of interacting for the parties involved in the project. (Korb et al, 2016).

Some of the primary subcontractors and suppliers, it should be noted may also be included in the multiparty contract. In this contract, all terms are clearly stated and normally include incentives and risk sharing, payment methods, parameter for dispute resolution, and the responsibilities of all involved parties (Li and Ma, 2017)

METHODS

To achieve the goal of this research and generate a lean production conceptual framework for a class of problems in PMC we employ the research method Design Science Research (DSR).

DSR aims to promote knowledge about projects and solutions development, solve problems and create new artifacts to obtain better project systems. Artifact being the interface between the internal and external environments of a system (Dresch, et al. 2015; Veit, 2013)

The underlying purpose of DSR is to develop knowledge for the design and realization of artifacts, to solve construction problems, and to improve the performance of existing entities, to solve improvement problems (Aken, 2001)

For this research the following protocol to be followed:

(1) A systematic review of the literature will be undertaken to raise awareness of the problem and identification of the artifact and configurations of the problem classes
(2) Empirical studies will be conducted in factories, to understand the barriers and potential solutions for workflow inside various case companies.
(3) Execution of the creative process based on the empirical studies with the proposition of artifacts that involve abductive reasoning;
(4) The deductive phase of the DSR will be carried out based on selection, development and evaluation of the artifacts;
(5) Explicit learning will be accomplished and conclusions drawn;
(6) As a result of this research, generalization will be achieved in the form of a conceptual framework so that the generated knowledge can be used to solve classes of problem.

The approach to the creation of a conceptual framework, which was similarly explained by Succar (2013) in his thesis as being a different condition from just testing existing concepts or theories, but rather should focused on the process of generating new theories. In this way, the bibliographic review carried out by the author provided the identification of a gap that is the integration between the different environments such as office, factory and construction site needed to the context of the PMC.

CONDUCTING EMPIRICAL STUDIES IN FACTORIES

Empirical studies are involve the collection and analysis of primary data based on direct observation or experiences in the field. This research involves empirical studies conducted in seven different companies.

Collecting information about the workflow and seeking to ascertain if there are gaps that are impairing the performance of these companies.

These gaps may be specific to a particular company or, in some cases, the same gap may appear in similar situations in different companies and such that the development of a conceptual framework can help PMC companies to achieve better workflow. Figure 2 summarizes some of the observations to be carried out as part of the empirical study.

Company	Business (Field of work)	Location	visiting date	Observation	BIM	OFFSITE (PMC)	OFFSITE (PANEL)	LEAN OFFICE	LEAN MANUFACT.	LEAN CONSTRUCTION	LEAN THINKING	LEAN PRODUCTION	IPD
Company A	Automotive	Brazil - São José dos Pinhais(PR)	2016	Worldwide car factory					•		•	•	
Company B	Naval	Brazil - São José dos Pinhais(PR)	2016	Handmade yacht factory									
Company C	Construction	Brazil - Araucária (PR)	2017	Woodframe panels factory	•		•		•				
Company D	Construction	Brazil - Ponta Grossa (PR)	2017	Light steel frame panels factory	•		•						
Company E	Construction	Brazil - Tubarão (SC)	2018	Permanent Modular Construction	•	•							
Company F	Construction	Spain - Salamanca	2018	Permanent Modular Construction and Relocatable Modular Construction		•							
Company G	Construction	Spain - Seville	2018	Permanent Modular Construction	•	•							

Figure 2. Empirical studies in factories

Among the companies visited, it was observed that the ones with a greater degree of automation of the production line were also the companies that were more closely aligned with Lean concepts, as in the case of company (A) from the automotive sector and also company (C) which produces prefabricated wood frame panels. It was observed that these companies have internal polices premised on Lean concepts.

Company (B), which is part of the naval sector and has the lowest degree of automation among the companies visited, is also the one with the lowest management over processes and also the company that has the least compromise with waste reduction and consequently is the one least aligned with Lean concepts.

The workflow analysis between companies (E) and (G) stands out for the reason that, although they are in different countries, these companies have a very similar workflow, demonstrating the potential for generalizability of the conceptual framework.

Company (D) and company (F), despite seeking industrialization through the offsite system, have a similarity that they both offer other products and services in their portfolio. Company (D) also works with automation for logistic system in addition to prefabricated Light Steel Frame and the company (F) also works with panels for facades, windows and doors in addition to PMC. In both cases offsite construction is not the primary business of the company. This relevant fact brought the perception that the focus was not complete on the challenges to be overcome in the search for continuous improvement of these companies, which serves as information in the structuring of this artifact.

According to Figure 3, these technical observations of the visits were extremely important in helping the authors to promote DSR and generate the conceptual structure.

Figure 3. Conducting empirical studies in factories

CONCEPTUAL FRAMEWORK

It is necessary to establish a favourable environment to promote a Lean Project Delivery for PMC, with characteristics that can be replicated in different companies.

Industrialized construction links at least three distinct workflow: the office, the factory and the construction site. These must be integrated using Lean tools such as Just-in-Time (Liker, 2005), Value Stream Mapping (Yu et al, 2009), Muda (Womack and Jones, 2003), and other existing tools to improve the level of integrating and synergy between these workflows. Figure 4 represents the work environments and workflow involved in PMC.

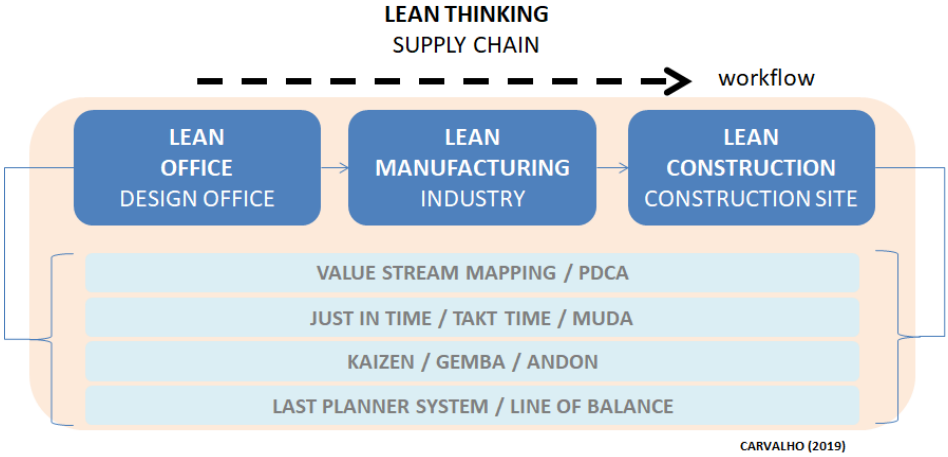

Figure 4. Lean as a model for integrating workflow between office, factory and construction site

Thus choices have been made by authors about which artifacts should be used to compose the deductive phase of the DSR such that a conceptual Lean Project Delivery structure for PMC could be developed to satisfy the objective of this research. Involving the offsite construction method with managerial aspects of Lean concepts for the design, manufacturing, transportation and assembly phases, united by an integrative contract model with clear goals to be achieved with risks and rewards for those involved in a search to complete the owner's objectives using

the primary source definitions of users. Figure 5 demonstrates the conceptual framework of Lean Project Delivery for PMC.

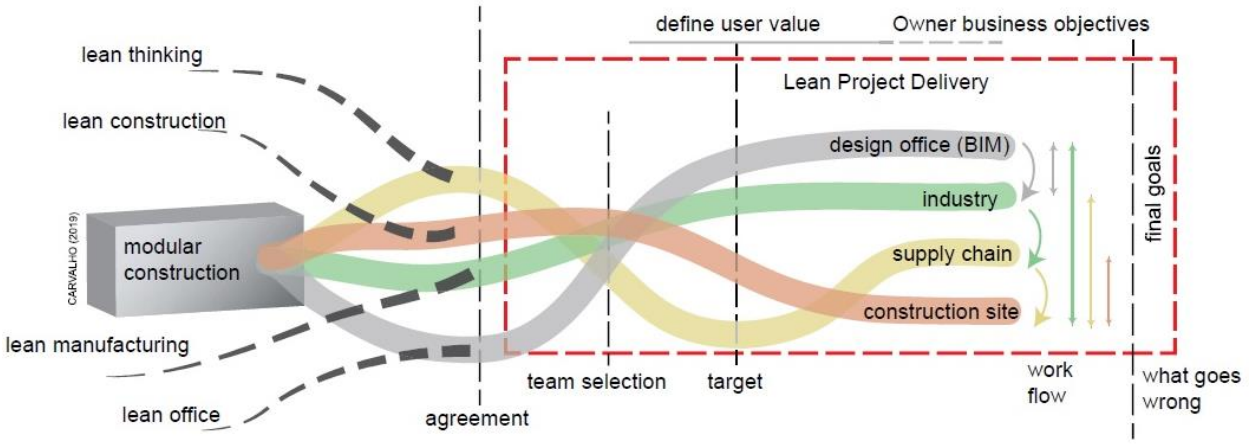

Figure 5 – Conceptual framework for Lean Project Delivery for PMC

Lean Project Delivery for PMC not intended to solve all workflows problems, but to promote integration of the workflows of different environments involved in modular construction and thereby increase the level of collaboration.

CONCLUSION

The artifact developed in this paper represents the intermediate stage of a broader research initiative, so it may undergo changes as the research progresses. Among the lessons already learned in this research, it is observed that the design, fabrication and assembly mechanisms of PMC may be similar in different countries. This points to the potential for integration of workflows from different enterprises and different jurisdictions and thus new business opportunities. The key outcome of this research date is the creation of a conceptual framework for PMC companies although this needs to be tested before an analysis of its performance can be carried out. The proposed conceptual framework is a trend to shape collaboration within PMC enterprises using lean concepts, BIM, and IPD.

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