JOURNAL OF LEAN SYSTEMS, 2019, Vol. 4, Nº 4, pp. 107-133

Analysis of the production function in civil construction: a driver for lean construction

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Article History:

Submitted: 2018 - 08 - 22 Revised: 2018 - 09 - 21 Accepted: 2018 - 10 - 06

Abstract: The construction industry has bleen an important role for economic growth, and gains in productivity could produce a significative impact. However, historically, it has been proved that this industry is operating not significativelly well in terms of efficiency related performance. The objective of this work is to justify the adoption of Lean Construction, as a comprehensive alternative for addressing problems related to resource and systemic productivity. To frame the productivity problem, the work analyzes the productivity of this sector, using the production function of Cobb Douglas, which is an econometric concept that provides information to assess relationships between the total volume produced, and the resources that are used during the production process. The present work has analyzed biggest companies in the world of civil construction, all of them listed in the Forbes 2017 publication. The production function analysis shows that these organizations are experiencing returns of decreasing scale. To address this results, this paper discusses the use of lean construction as a feasible alternative to increase productivity, considering the effects that operations networks and supply chain level could produce in the aggregate level of industry performance.

Keywords: Production Function; Construction; Lean Construction; Productivity

1. Introduction

The Report from the World Economic Forum for Urban Development and Infrastructure - WEF (2016) shows that the construction industry has been slower in incorporating technological innovations when compared to other sectors, which directly reflects its productivity issues. On the other hand, there is considerable room for growth in this sector considering that the world population grows in 200,000 people per day, and at some point, these people will need additional housing, transportation and utilities infrastructure. Moreover, in economic terms a 1% increase in the productivity of this industry worldwide could result in savings of up to US$ 100 billion/year. However it also stands out as a sector presenting frequent problems related to low productivity and low quality indices, to name a few (Abbasian-Hosseini; Nikakhtar; Ghoddousi, 2014).

It is worth emphasizing that the productivity of a certain sector depends on the economic health of the analyzed local context. In addition, productivity is not influenced by a single factor but the result of a combination of aspects such as technology used by the company, the infrastructure offered by the public sector, and even the management techniques adopted by the industry (Iona, 2009).

In his work, Hassani (2012) discusses the many unplanned costs that affect a construction site and which are often not questioned, as they are usually justifiable due to the pressure to finish the work within a short period of time. The author also points out the great number of research studies that explore the trade-off between time and cost in construction projects. However, only a few cases explore the origin of these costs in depth and discuss the importance of using the production function of Cobb Douglas to understand the real need for resources, whether labor or equipment, to complete a work within schedule. This is because the production function provides the relationship between the input resources and the generated outputs. De Angelo, Silveira e Tanabe (1990) have emphasized the importance of the production function for the management of operations, as it serves as an index that reflects the need to intensify the use of resources, whether financial (assets) or labor (number of employees). In cases where the production function demonstrates that there is decreasing economy of scale, it is up to the manager to seek alternatives to improve their productivity without increasing resources.

According to Galbraith; Nkwenti-Zamcho (2005), productivity is a measure that analyzes the rate of input resources versus the outcome of the processes. The two characteristic features are divided into human and non-human resources (these refer to equipment, structures, stocks etc.). Using a Douglas Cobb type function, the authors have analyzed the productivity of 3 companies and certain factors that had an impact on them, and concluded that equipment maintenance and workforce training had a positive impact on productivity. Although they have not explored lean manufacturing, when implementing a lean operation both aspects are considered.

Lieberman e Dhawan (2005) show the gains in productivity that auto producers are promoting by the adoption of lean manufacturing techniques and models. They develop an analysis based on estimation of sthochastic frontier production function, relate to the use of resources and the efficiency among the firms of the study.

However, the WEF (2016) points out that these types of actions in construction are relatively rare. Whenever incorporated, lean production tools tend to have little coverage. For example, although lean concepts are already in wide use in other industries, the level of use of this particular system can be strongly increased in construction. This is bad for the industry because the use of lean principles and tools could lead to a 30% reduction in the execution time of a particular project, as well as a 15% reduction in costs.The main objective of this work is justifying the need of Lean in the civil construction industry. It is uses two different research methods, in the first we use the production function, and after we did a systematic literature review to found success case of the Lean Construction use.

In this context, this article evaluated the productivity of the world's largest construction companies according to Forbes 2017, and compared it with the automotive sector-benchmarking for Lean. It is important to emphasize that this article won't discuss the conceptual aspects of the production function theory, but it applied the conceptual basis that is already consolidated two different industries to illustrate how an industry that uses lean techniques presents better results with regard to the use of its resources than an industry that still arouses interest in lean.

From this result this article intends to emphasize the importance that the process of diffusion and incorporation of the lean construction.

The discussion is organized as follow. This article has calculated the productivity of the biggest construction and auto and truck manufactures in world, using the production function of Cobb Douglas to conduct the calculations. We have considered the companies listed in the publication Forbes: The Worlds Biggest Public Companies 2017. In addition, we have carried out the analyses through a systematic literature review as lean concepts can help the construction sector to increase productivity.

2. Literature review

2.1 Production function: basics concepts

According to Gujarati and Porter (2011), the function of Cobb Douglas originates from the theory of production. It is a log-linear model that considers the labor input, capital input the stochastic error term and the natural-based logarithm in its stochastic form, as follows:

$$Y_i = \beta_i X_{2i}^{\beta 2} X_{3i}^{\beta 3} e^{ui}$$

In which X2= labor input and X3= capital input.

Gujarati and Porter (2011) have pointed out that in their stochastic form, production functions are not linear and propose the logarithmic transformation of the variables as alternative. Therewith, the function assumes the following form:

The transformation leads us to work with a linear model that allows the use of linear regression concepts. In relation to the properties of the Cobb Douglas function, coefficients β2 and β3 represent the partial elasticity of the product in relation, respectively, to the labor input and the capital input; their sum informs us on the returns of the scale. That is, if:

- $\beta 2 + \beta 3 = 1$, one can assume the sector studied has constant return of scale;

- $\beta 2 + \beta 3 < 1$, one can assume the studied sector has descending return of scale;

- $\beta 2 + \beta 3 > 1$, one can assume the studied sector has ascending return of scale.

In addition to the production function analysis, generally some tests are use.

The test of comparison of variances (Test F), could be confirme the existence of a functional relationship between the variables. In other words, Test F tests the hypothesis:

- $H0 = \beta 2 = \beta 3 ... = \beta K = 0$;

- H1: not all angular coefficients are simultaneously equal to zero

The analysis of this test consists of verifying that $F > F\alpha$ or, if the obtained p value is sufficiently low, then H0 is rejected.

The Ramsey RESET test is to verify whether there were specification errors in the proposed model. It is important to analyze whether the model is linear, as the adopted theory refers to linear models.

If the research works with financial data in cross-section, it is important to analyse the concept of heteroscedasticity that among other things indicates asymmetry in the distribution of one or more regressors. However, it is worth emphasizing that all these tests only make sense if the data are normal.

2.2 Lean construction

On the one hand, much is discussed about the applicability of lean concepts in civil construction. On the other hand, the need for this sector to improve the efficiency of its processes is latent, so even with certain differences, lean systems have been gaining space in construction, where it is applied under the name of lean construction.

According to Sage et al. (2012), lean systems used in civil construction emerged as a strategy to help reduce project costs and predict the time for their completion, as well to directly affect quality in construction, improving relations in the supply chain and the relationship with customers.

Miranda Filho et al. (2011) believe that construction managers have difficulty understanding that several adjustments are required in the production strategy in order for the productive system to be successful, and that this has a direct impact on the performance of lean construction. One way to solve this problem would be to analyze the adoption of best practices. However, it is usually not clear why a particular company opted for a particular practice since in most cases, best practices are implemented as isolated tools. It is important that companies have the understanding that a certain practice becomes a "best practice" under a specific context, and thus represents the end result of the combination of contextual and organizational factors.

Zimina and Pasquire (2011) point out that until the 1990s, construction companies had no reason to invest in the improvement of their internal processes. However, after the financial crisis in Europe in 1990, customers started to have a greater bargaining power, demanding higher quality at lower prices. This fact has created a need for the companies to improve their internal processes, and lean construction in turn improves internal profitability by improving operations.

However, it is important to emphasize that according to Koskela et al. (2002), the product from civil construction differs from other manufactured products in many respects, mainly because the latter can be moved to the final customer, whereas in the case of construction this is impossible. In addition to this characteristic, there are three other differentiations that deserve highlight: production is done locally, projects are unique and involve a high degree of complexity.

One advantage of manufacturing over construction is that its processes are mostly repetitive, and while the company replicates the same activity it specializes and improves execution, whereas in construction this does not occur, as the great majority the projects are unique.

Salem et al. (2006) have pointed out that the extension of techniques from manufacturing to construction still poses unanswered questions. It is clear in both contexts that the combination of human work with technical elements ensures better performance. However, it is important to determine the set of tools that can be applied to achieve the best performance in construction projects.

According to Koskela (1992), (one of the first publications about lean construction), the construction process uses raw materials as input and offers an end product as output, and the processes are formed by transportation, waiting, construction and inspection activities.

In order to manage these processes and eliminate wastage, the author proposes 11 principles that guide most lean construction projects, namely:

- ✓ Reduction of activities that do not add value;
- ✓ Identification of internal and external customer requirements that increase the value added to the final product;
- ✓ Reduction of variability;
- ✓ Reduction of the cycle time;
- ✓ Decrease in the number of steps and parts with consequent simplification of the process;
- ✓ Flexibility of process outputs;
- ✓ Transparency in the execution of processes and recognition of errors;
- ✓ Management of the process through indicators;
- ✓ Implementation of a culture of continuous improvement;
- ✓ Balancing stream improvement through improved conversions;
- ✓ Performing benchmarking

When comparing Koskela's principles to lean construction with Womack and Jones's (5) steps for manufacturing, we find that both are very similar and although Koskela's 11 principles are more detailed, they can be considered an extension of the work of Womack and Jones.

3. Method

According to Thiollent (2009), in order to reach a specific objective in research, it is necessary to choose a method to find the appropriate techniques for collecting research data, concepts to be used, etc. among the information available in the bibliography.

Two different methods were used for the development of this research, for this reason the method will be presented in two phases: phase 1- quantitative study and phase 2- qualitative study.

3.1 Phase 1 - Protocol for the productivity study

The study of productivity began with the choose the data. we choose the biggest civil construction listed at Forbes to represent the sector, and we did the with the auto manufactures.

Data collection was secondary in this work, and the data was used as a source, available at <https://www.forbes.com/global2000/list/#tab:overall>. Through the magazine's website, it was possible to filter by companies in the construction services sector and auto and truck manufactures. The sample contained a total of 53 construction companies and 30 auto manufactures, and based on the data of these companies, the production function was adjusted through a cross section analysis.

Since one of the objectives of this work was to adjust a production function for these companies, the following data were collected for year base 2017:

- ✓ Sales
- ✓ Market Cap
- ✓ Number of employees (headcount).

The PCGIVE 10.3 software was used to perform an analysis of the sample data.

In addition to the production function analysis, the value of the correlation coefficient between the model variables was also analyzed, and the Test F, Ramsey and Heterocedasticity was used.

3.2 Phase 2 - Protocol of the systematic literature review

The objective of the systematic literature review was to explore how lean construction can help the construction industry to improve productivity.

Based on the theoretical grounds, it was established that search strings should contain the words “lean construction” and “productivity” either in the title of the paper, in its abstract or in the keywords.

Next, it was defined that the searches would be carried out on the following bases: Ebsco, Web of science, Taylor & Francis, Science Direct, Emerald Insight and Scopus. The choice of databases was based on their importance and scope for the area of operations management.

The works had to fulfil the following criteria to be included in the analysis:

- ✓ Articles available in scientific journals
- ✓ Articles in either Portuguese or English
- ✓ Articles that contained the key words: lean construction and productivity in their title, abstract or key words.

Based on these criteria, the search was carried out and soon after the reading and processing of the papers, the works moved on to process the analyses in two stages.

The first was to cluster the works and to eliminate duplicates.

The second was to read the abstract and the introduction, the articles that the main focus was on robotic solutions, game theory, simulation and mathematical modelling, they were excluded. These exclusion criteria were established because the focus of this review was to provide subsidies that lean construction can help in improving productivity, and when based in other theories, the articles would then divert from the proposed scope. The Table 1 presents the summary of the structure adopted to conduct the systematic literature review.

The articles that met all the criteria proceeded for complete reading. After this stage, the works that did not contribute to answering the question that this article proposes have been eliminated. In addition, it was not possible to access the full text of two articles. The result of the systematic review is shown in section 4.2.

Table 1 - Summary of the structure of the Sistematic Literature Review

Structure of the Sistematic Literature Review	Define de research question	How lean construction can help the construction industry to improve productivity?
	Define the search strings	Title or Abstract or Keywords contain the words " Lean Construction" and "Productivity"
	Define the data bases	Ebsco, Web of science, Taylor & Francis, Science direct, Emerald Insight and Scopus
	Define the criteria inclusion	Articles available in scientific journals; Articles in either Portuguese or English; Articles that contained the key words: lean construction and productivity in their title, abstract or key words.
	Define the criteria exclusion	Articles that the main focus was on robotic solutions, game theory, simulation and mathematical modelling

4. Results

The results of this study will be presented in two sections.

Firstly, it presents the result of the productivity function for the construction industry around the world and it is compared with the productivity to automobilistic sector. This stage illustrated how an industry that uses lean techniques to present better results than an industry that still arouses interest in lean.

The next session presents the results of a systematic literature review. This session compiled the effects of several lean applications in the construction industry, illustrating the productivity gains that the use of this system brought.

4.1 Analysis of the production function

The data about construction firms used in this work are available on Forbes, this firmes was considered the biggest world's construction service, the same criterious was used for the auto and trucks manufacturers, all the enterprise are larger firm.

It is possible to observe in Table 2 that the companies in the civil construction sector were decreasing scale return, since the sum of the labor and net worth coefficients are equal to 0.75 <1, i.e. a 10% increase in the variability would bring a 7.5% increase in production. It was verified an even lower return on capital input, as a 10% increase would bring a 2.6% increase in net sales.

The interpretation of these data refers to the theory of gains in scale, and through the analysis of these coefficients it has inferred that the limits of gains of scale seem to have been extrapolated for these companies. This aspect reinforces the need for companies to invest in improving their processes and increase production, however without increasing their resources but taking advantage of them more efficiently. Since the results suggest that the use of productive factors in this sector has not been done efficiently.

Table 2 - Production Function for Construction Industry

	Coefficient	Part. R^2
Constant	0.360237	0.0405
LMktCAP	0.266993	0.0918
LEmployers	0.499614	0.5068
R^2	0.668574	
Test F	F(2,49) = 49.42 [0.000]**	

The degree of explanation (R^2) for net sales through the companies' shareholders' equity and their number of employees was 66%, and according to the results the labor variable has greater impact on productivity: 49% for companies of the construction industry. This was already expected, as one of the hallmarks of construction is the intensive use of labor, which is often poorly allocated since this sector tends to intensify this strategy to solve problems of technological development and management of the productive processes.

In relation to the F test, the null hypothesis was rejected, i.e. in this case the regressors influenced the regressed, which is confirmed by the high R^2- 66% .

For the auto and truck manufacturers listed in Forbes for year 2017 it is possible to observe, in the Table 3, that this sector presented increasing economy of scale, this result suggests that their efficiency in the use of productive factors is higher than in the construction industry.

Table 3 - Production Function for Auto Industry

	Coefficient	Part. R^2
Constant	-0.915434	0.0868
LMktCAP	0.517789	0.1919
LEmployers	0.670401	0.3663
R^2	0.712855	
Test F	F(2,27) = 33.51 [0.000]**	

Although there are other aspects that may justify the difference in efficiency in the use of the factors of these two sectors, Lieberman and Dhawan (2005), when conducting an analysis of RBV within a production function model of firm performance for auto producers, they included a lean production proxy represented by work in process/sales, then they could observe that higher levels of WIP were associated with lower levels of efficiency. One of the conclusions of this work was that the use of Lean reflects on a better production function result.

In the civil construction literature, it is possible to find a lot of productivity studies, Kapelko et al. (2015), for example, studied the productivity of the Iberian construction industry between 2002 and 2012, and found that productivity declined, alerting the managers of this region to the need to improve the performance of these firms.

Howeel, Ballard, and Tommelein (2011), emphasize that the issue of improving productivity is not new to the civil construction sector. However, in order to achieve this goal, the traditional approach works to reduce the duration of activities, which often means allocating more workers to perform a specific task (consequently increasing costs), while the lean approach focuses on optimizing the project as a whole.

It is noticeable that there is already a conscience in the construction sector that the productivity of the same presents opportunities to improve, fact that even highlighted as being a necessity of the sector for the report of World Economic Forum WEF-2016.

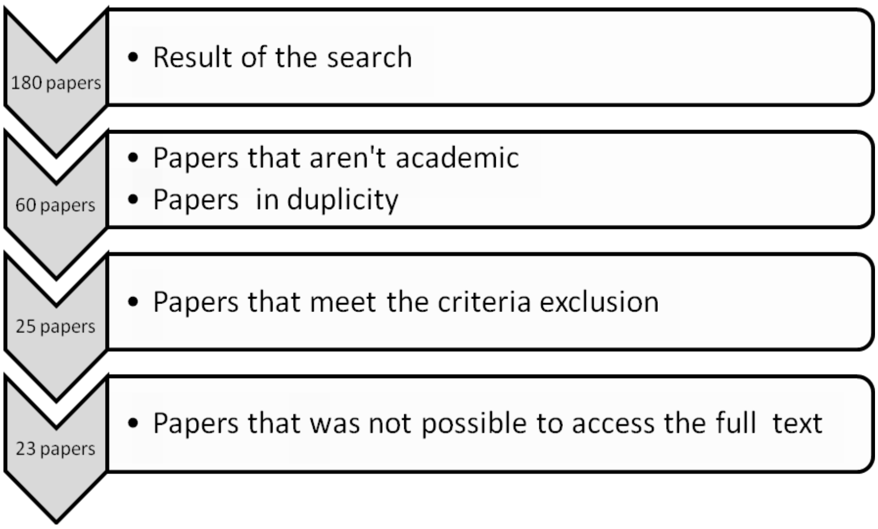
However, there are few works that explore the causes of this inefficiency. As has already been done in the automotive sector, evaluating construction productivity and suggesting construction creation, it may be the impetus for this industry to direct its efforts to implement this system and consequently feel the improvement of their processes.

The difference of this article for many others productivity studies, like Kapelko et al. (2015), Abbot and Carson (2012), Tan (2000) for example, it is the focus on the proposition of lean as an alternative to improve the performance of the sector. For this reason, in the next section will be presenting a set of results obtained through a systematic review of literature, which describe improvements at the firm level, through the use of the principles of lean in civil construction industries.

4.2 Systematic literature review

The objective of the systematic review was to seek subsidies that prove that lean construction may be a path in the pursuit of increased productivity in the construction industry, after processing the work, according to the Figure 1, it was determined a set of 23 articles.

Figure 1 - Steps of systematic literature review

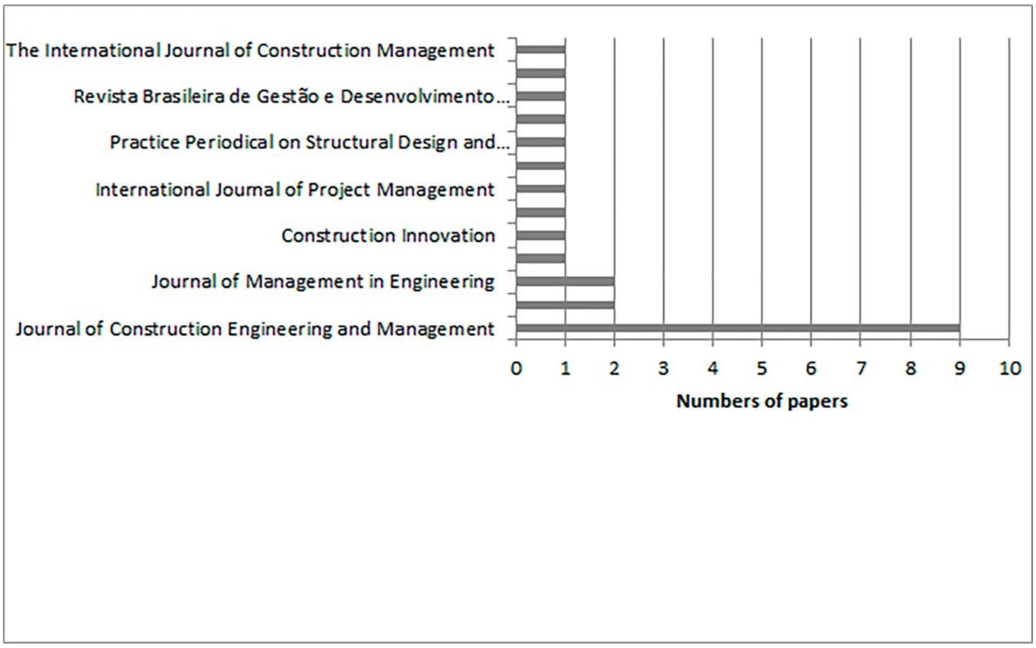


Initially it observed three general characteristics in the articles: year of publication, in order to understand how the subject evolved; the country of origin, as it would allow to make considerations about the diffusion of the subject around the world; and finally the papers in which the theme was more recurrent.

As for the year of publication, Figure 2 shows that there have been publications on the subject since 2002, and the largest number of publications occurred in 2011, post-crisis period in the USA and Europe, which makes sense since it is common for companies to use new techniques and dedicate themselves to implementing them in periods of difficulty. The Toyota system gave rise to lean thinking, and gained momentum in a period of crisis in the Japanese industry.

In terms of the journals in which the works are published, the majority of them are diffused across several journals, although the Journal of Construction and Management seems to have given special attention to the subject, accounting for 35% of publications.

Figure 2 - Number of publications according to the Journal



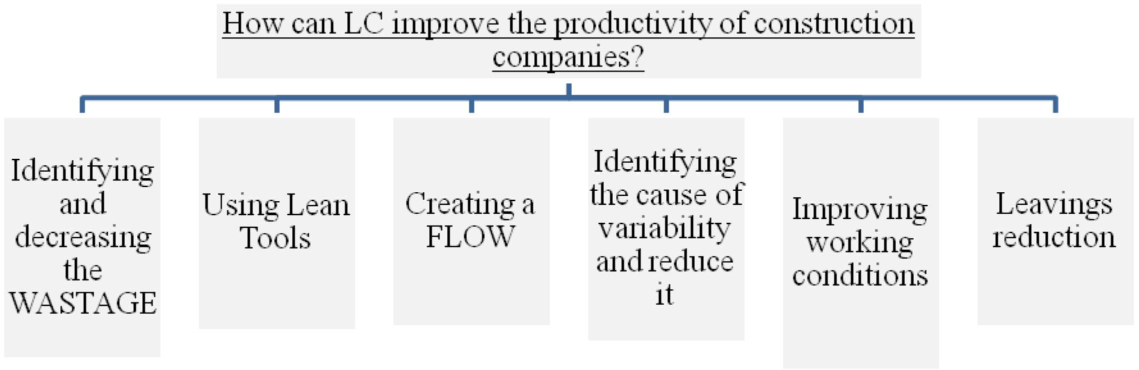
As for the countries these publications originated from, whenever the country of research was not described in the article, it was considered the country of the first author of the study. In addition, it was possible to realize that the subject lean construction and its contribution to productivity are already present in countries across different continents.

The country with the highest number of publications is the United States, followed by Brazil and the United Kingdom. Together they are responsible for 65% of the studied publications but there are also studies from Israel, Egypt, China etc. This analysis suggests that many countries are already interested in lean construction as a solution to productivity problems.

After this initial explanation with the general characteristics of the articles in the studied sample, we have observed that many authors deal with the subject from different perspectives. Some emphasize the opportunities for lean implementation in construction, others address certain crucial points that differentiate traditional management from lean systems. The importance of labor in this process was also recurrent, and certain studies have even described the results obtained from the application of lean systems.

In general lines, it was found that lean can help improve the productivity of the industry as fas as reduce waste, some of its tools solve problems of organization of the work, improve planning , working conditions, however, there is a consensus among most authors that the greatest benefits of LC-Lean Construction are related to knowing the causes of variability in order to reduce it, and it creating a flow in construction as well as differentiate flow activities from those of conversion. The Figure 3 presents a summary for the answer of the question: How LC can assist in improving productivity?

Figure 3 - How LC can assist in improving productivity?



The Table 4 presents the relationship between the authors and the main idea of their respective papers.

Table 4 - The relationship between the theme of the article and its authors

	Decreasing the wastage	**Using lean tools**	**Creating a flow**	**Reduce variability**	**Improving working conditions**	**Leavings Reduction**
Abdel-Razek et al. (2007)	✓		✓			
Aziz; Hafez (2013)	✓					
Borges et al. (2008)		✓				
Castillo, Alarcon and Gonzalez (2015)		✓				
Court et al. (2009)		✓				
Dunlop and Smith (2004)			✓	✓		
Gallardo, Granja and Pichi (2014)		✓				

	Decreasing the wastage	**Using lean tools**	**Creating a flow**	**Reduce variability**	**Improving working conditions**	**Leavings Reduction**
Gao et al. (2014)		✓				
Howell, Ballard and Tommelein (2011)			✓			
Ikuma, Nahmens and James (2011)					✓	
Liu et al. (2011)				✓		
Lu, Guo and Skitmore (2012)	✓					
Marhani et al. (2012)						✓
Nahmens and Mullens (2011)				✓		
Ogunbiyi et al. (2014)				✓		
Pheng, Gao, and Lin (2015)		✓				
Ruppenthal et al. (2015)		✓				
Sacks; Goldin (2007)	✓		✓			
Thomas and Horman (2006)			✓			
Thomas et al. (2002)			✓	✓		
Thomas et al. (2003)			✓		✓	
Yu et al. (2013)			✓			

In the following sessions will be detailed how each one of these subjects was approached by the respective authors.

4.2.1 Lean Construction could help to identifying and decreasing the wastage

Li, Guo and Skitmore (2012) emphasize that the productivity of the construction industry has decreased worldwide in general. In order to reverse this scenario, the authors advocate the use of lean construction. However, there are barriers that hinder success in the implementation and dissemination of lean construction: the first refers to the difficulty of understanding the concepts, the separation between design and construction processes that hinder the accuracy of planning, and the communication between the different agents in the construction chain, as required by lean systems.

According to Abdel-Razek et al. (2007), the construction environment generates a lot of wastage, which makes it difficult to measure it in its totality. However, this aspect has a negative influence on performance and productivity indices. It is therefore of the utmost importance that this environment be better understood and such wastages, when not disposed of, at least be managed.

Sacks and Goldin (2007) studied building construction and identified various types of wastage such as: unwanted products (standard apartments that do not attract consumers), general rework, inventory, unnecessary activities, unnecessary movement of workers and materials, waiting for materials and information, and properties that did not meet customers' needs and had to undergo modifications.

Aziz and Hafez (2013) point to lean construction as a viable way to identify and eliminate waste. This initiative consequently improves productivity and effectiveness in the construction industry.

4.2.2 The use of Lean Construction tools could help to improve de productivity

Borges et al. (2008) point out that although the construction projects are unique, it is possible to find situations of repetition from which we obtain a pattern for the construction of buildings. The authors carried out a study on building constructions in Brazil and, although they did not present quantitative measures, they have concluded that it is possible to have an increase in the productivity of the civil construction through the use of the mapping of the value flow, as well as the use of Kanban systems.

4.2.3 Creating flow could help to improve productivity

According to Howeel, Ballard, and Tommelein (2011), both the traditional approach to construction management and lean construction advocate the need to deliver value and reduce wastage. While the former's operating system focuses on performing the activities, lean systems seek to create flow. Similarly, Abdel-Razek et al. (2007) point out that the difference between the traditional management system in construction and lean construction is that the latter sees production as formed of flows and conversions, where conversions relate to what adds value to the customer, and the flow refers to conversion, wait inspection, and handling activities. Understanding the process flow and avoiding interruptions to reduce variability is one of the main aspects of lean thinking (Thomas et al. 2002).

According to Dunlop and Smith (2004), knowing how to differentiate flow and conversion is essential for decreasing the cycle time, since one way of doing this is by reducing flow activities, or even eliminating them when the analysis shows it is possible to exclude them.

In traditional construction management, it is assumed that the allocation of activities and the duration of activities can be planned in deterministic fashion. However, it is difficult to carry out the activities as planned, since there are not always equipment and people available to carry them out at the required moment. In addition, it is common to have variability in workforce productivity due to the learning curve, variations that may occur in the design of one apartment or another and the flow of information that is rarely available as planned (Sacks and Goldin 2007).

Gao et al. (2014) have carried out a case study and found that material management is still a critical issue in construction, because not all the assumptions adopted at the beginning of a project actually coincide with reality, thus causing delays. The basic assumption was often that a given material would be available within the requested specifications. However, at the time of its use, the team would verify that the specifications did not match. Alternatively, there was the assumption that the supplier would deliver the material on a certain date, which did not happen etc. In light of this, the authors suggest that the assumptions be checked beforehand, prior to the given point in the project when the necessity will arise, avoiding possible unforeseen delays.

In this sense, lean construction through the use of the last planner tool helps construction managers to reduce the degree of uncertainty of a project as they carry out all the programming before the activities occur. In addition, they consider elements such as stock and movement of materials, handling and availability of equipment, workflow and team skills, availability of information, safety of external factors, site safety throughout the project, applying the concept of work prioritization.

4.2.4 Reducing process variability could help to improve productivity

According to Thomas et al. (2002), there are three aspects that influence the efficiency of a construction project: available necessary resources, appropriate conversion technologies and no interruptions. In turn, lean construction enables the reduction of variability coupled with an increase in flexibility, improving the productivity of the construction project.

Dunlop and Smith (2004) point out that in order to improve productivity using lean principles, it is necessary to know the variables that interfere in the cycle time of the studied process in depth. After an analysis by several authors, Nahmens and Mullens (2011) point out that one of the biggest problems in construction is variability, which may originate from delays in the delivery of materials and equipment, project errors, changes throughout the project, inadequate management of workforce, environmental problems, and the very common customization in construction projects.

4.2.5 Improve working conditions could help to improve productivity

According to Ikuma, Nahmens and James (2011) two of the main problems in the construction sector come from low productivity it is high damage rates. In this environment, the use of lean tools, in addition to improving the process itself, can lead to improvements in worker safety, thus reducing the damages caused by accidents.

According to Ogunbiyi et al. (2014), lean construction has been used to improve safety at work, providing the materials and workforce needed to perform the tasks as they are needed.

4.2.6 Leavings reductions could help to improve productivity

Marhani et al. (2012) consider that LC both helps to improve the productivity of construction and helps this industry to be more sustainable, as lean systems facilitate processes to generate less wastage and more efficiently use the available resources such as energy, labor etc.

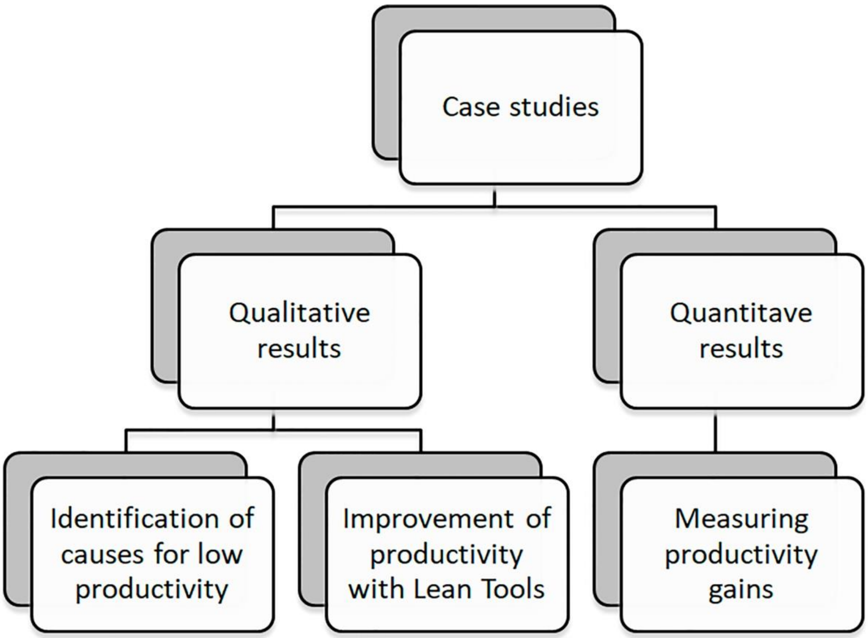
According to Marhani et al. (2012), one of the major benefits of LC is to reduce construction costs through the use of correct materials. However, it is important not to misinterpret this view, so that the LC is not interpreted by a substitution of materials with cheaper items that could jeopardize the safety of the project or its quality. It is necessary to emphasize that the core of the lean philosophy is to satisfy the customer.

4.3 Results obtained with Lean Construction application

Given the possibility of increasing productivity in construction, many authors have explored the application of lean thinking or of certain isolated tools from this philosophy, and analyzed the results, thus corroborating the hypothesis that there was an improvement.

The results found in the case studies are diverse, as shown in Figure 4.

Figure 4 - Typification of the results of the case studies



4.3.1 Cause for low productivity in construction

Abdel-Razek et al. (2007) suggest benchmarking actions and reduce the variability of work allocated to workers in order to increase productivity. Through case studies of 11 construction projects in Egypt, the authors observed the problems that influenced the project included material loss, inefficient communication and inadequate supervision, and they have also verified that certain clients were dissatisfied with delays and quality issues. Another question raised refers to the inherent variability of the studied projects, and to reduce variability the authors suggested that the workflow, planning, information flow and feedback systems should improve.

Ikuma, Nahmens, and James (2011) have conducted a case study of the implementation of lean construction in a modular house construction project that presented three problems: inadequate material, variable production between workstations, insufficient workforce. After identifying the problems, they have studied and implemented certain solutions, and they have verified that after improving the process, in addition to increasing productivity for the company the activities also became safer to be executed by the employees.

4.3.2 Examples of increased productivity using lean tools

Court et al. (2009) have presented a study in which lean tools are used in a construction company with the objectives of improving workers' safety and increasing company productivity. Initially, the authors have observed a lot of disorganization, making the ordered storage of parts and tools rather difficult, and this often generated delays.

During the construction of a hospital, three principles were applied: zero work accidents, project design as an assembly line, use of available technologies (such as 3D modeling). In order to achieve this goal, the authors have used certain concepts commonly used in lean manufacturing, for example they extinguished the central warehouse for the project and used the formation of daily kits with all the required tools for the workers to avoid unnecessary movements.

The project also invested in the definition and implementation of supply routes. Although the authors do not present a quantitative measure of productivity in this article, they state that it has improved as working conditions have improved.

Pheng, Gao, and Lin (2015) have compiled their work on how early contractor involvement can improve productivity in construction projects by establishing a communication system between agents, improving plant management, carry out the design based on realistic construction capacities, observing increase in the innovation and use of creative techniques to solve problems, reinforcement in constructability, reduction of variability, clear and fast start of the work.

The authors emphasize that lean construction can maximize civil construction productivity through early contractor involvement (ECI) because ECI facilitates reduced variability, cycle time, step minimization and leads to increased flexibility.

Yu et al. (2013) carried out a case study in a modular building company for civil construction. The authors have chosen a pilot area and the first actions consisted in the implementation of 5S and establishment of the workflow. The importance of starting by the implementation of 5S was highlighted as an extremely visual tool and requiring the involvement of all beyond what involves the application of other tools such as standard work and visual management. After the incorporation of lean techniques, the authors have verified an improvement in productivity and a reduction of wastage.

Ruppenthal et al. (2015) conducted an empirical study in Brazil in which they verified how the use of lean practices improved productivity in a horizontal housing project. The tools used had positive results and consisted in the reduction and simplification of the steps and parts in the processes of plates and linings of PVC, Kanban in the process of making the electric whips, use of the concept of assembly of kits ready to be installed as for the electrical installations and hydrosanitary in the radiers and walls.

Based on the foregoing, there is no doubt that productivity in construction can be improved through the implementation of lean construction. This fact can be illustrated quantitatively by the works of Dunlop and Smith (2004), Nahmens and Mullens (2011), Gallardo, Granja and Pichi (2014), Castillo, Alarcon and Gonzalez (2015).

4.3.3 Quantitative results described in the case studies

Dunlop and Smith (2004) studied the influence of the adoption of lean principles on the productivity of the construction industry, more concretely in the concreting process. Among lean principles, the authors argue that those that most adhere to the needs of this process is the reduction of variability and cycle time. According to the authors, the use of the JIT concept would directly influence the productivity of this process, because in order to achieve maximum productivity during the concreting it is necessary to have the number of trucks mixing enough quantities for the area to be covered and the concrete pumps available and working.

During the study of the case in two different projects, Dunlop and Smith (2004) used the time spent to pour the cement, the area covered, the time of pumping, the interval between the arrival of trucks on the site, the queue time of the trucks, and the time spent for the trucks to position themselves correctly as measures for the concreting process. At the end of the 202 observed discharges, they found that the time spent in activities that did not add value was much higher than that spent with activities that did add value to the project.

Dunlop and Smith (2004) verified in their study that if lean tools had been used during the concreting process the productivity could have increased by up to 25% with simple activities, basically consisting of the elimination of observed wastage (truck queuing time, waiting time for arrival of a new loaded truck).

Nahmens and Mullens (2011) conducted a case study in a cement pre-fabrication company, and identified that 47% of the time spent by the workforce was on activities that do not add value to the product (basically reworking, waiting for instructions, searching for tools and materials etc.). After conducting a kaizen project, the company had a productivity improvement of 47%.

Gallardo, Granja and Pichi (2014), through an action research carried out in Brazil, have implemented certain lean tools in a production line of pre-fabricated concrete tiles. There was a visible improvement in productivity after the implementation. However, the results were unstable, creating what is commonly known by false flow.

In light of this result, the authors used a visual management framework to control the production and obtained improvements with this tool, since its use developed a sense of ownership over the tasks performed in the team, so that the team leader would note any deviation from the plan and ask for help whenever necessary. Therefore, it was possible to stabilize the process, since any deviation from the plan was recorded and the problem was then analyzed and resolved. At the end of the project, productivity increased by 25%, and the authors concluded that the use of lean tools such as VSM, 5S, pull system, TPM, Kanban, visual management etc. could help improve productivity.

In the work presented by Ballard et al. (2003), the authors highlighted the gains obtained by a construction company after incorporating the concept of production cell, drawing attention to the improvements obtained from the autonomy given to the workers in the process of suggesting modifications that could improve the performance of processes. With the experience of cell implementation, the authors measured a productivity improvement that reached 180% in a wall shear production cell. According to Ballard et al. (2003), there were no changes to the production methods or incorporation of no new technologies, they only adjusted the productive system, which brought considerable gains in productivity.

Castillo, Alarcon and Gonzalez (2015) carried out a case study in a mine project, in which they have used indicators and evidenced that the productivity of the project increased by 37% due to the use of lean tools. In order to obtain this result, the project used tools and methodologies such as identification and reduction of wastage, investigation of delays, last planner, VSM, visual controls, 5S and continuous improvement.

5. Conclusion

The analysis of the production function for the sector provides subsidies that productivity, at least for the companies of the studied sample, faces a scenario of decreasing economies of scale. In view of this scenario, lean construction is an option for these companies to improve their processes, consequently increasing productivity, however without having to invest in new resources.

As observed from the systematic review of literature, lean construction can contribute significantly to the increase of productivity in the sector. Certain articles have included case studies with results that corroborate this theory, both presenting quantitative and qualitative results in this second group. Some of them address the observed causes that have a negative impact on productivity and could be solved with lean tools and systems. Others describe the implementation of certain tools that brought good results but these were not listed.

It was possible to observe that lean construction allows an improvement in the processes through the use of its tools in the selected works, for example by enabling the calculation of the exact number of professionals needed in a given construction site, or through the use of the work standards that contribute to the reduction of defects and errors in construction. It is also possible to consider the fact that by promoting a more organized work environment helps to reduce accidents at work, etc.

As the main objective of this work is to draw attention to the importance of incorporating the concepts of the LC in its processes, the productivity of the automotive companies listed in Forbes 2017 was also calculated, because the Lean was born in this sector, which can be considered the benchmarking of this system.

From the analysis of the Cobb Douglas function, it was verified that the civil construction sector presents a diseconomies of scale, in contrast to the companies in the automobile sector that presented economies of scale.

This result shows the need for this sector to use its resources better, since the Cobb-Douglas function relates the process inputs to their outputs.

These result attentivelly to the need to reflect for the exclusive use of the traditional approach of the management by projects used in the construction, since in this approach usually when it is necessary to increase the productivity a measure to be taken refers to decrease lead time through the allocation of more workers.

However, in a context of decreasing economies of scale, as was verified for this sector in the year 2017, allocating workers, or increasing investments in resources doesn't proportionally reflect productivity, it is interesting in this scenario that innovative solutions are sought.

In this context, this work advocates a broad incorporation of Lean Construction as an alternative to increase the productivity of the construction sector.

In order to corroborate this proposal, a systematic literature review was carried out in six different research bases, which resulted in 23 articles that answered the question of research: Can Lean Construction improve the productivity of construction?

The answer was "yes." The case studies found in the systematic literature review presented empirical results demonstrating that LC implantation improved the productivity of those constructors.

This is because, by facilitating the construction planning and control process, through the use of the Last Planner, the LC improves the accuracy of planning, consequently reducing delays and their consequences (customer dissatisfaction, contractual penalties, miscellaneous damages).

In addition, actions to improve the supply of materials, both internal and external, using kanbans, supply kits, programming of external deliveries, establishment of a place for delivery of materials, reduce interruptions of the work, consequently increasing productivity.

One of the pillars of the LC is the establishment of continuous flow, reducing unplanned shutdowns, which is precisely one of the negative aspects most emphasized by the authors to justify the low productivity of the construction, either by lack of materials or even by work accidents.

In this context, the use of tools that improve the work environment, such as 5S, help both the reduction of accidents involving workers, as well as the time spent cleaning the work, searching for materials and tools, etc.

In other words, LC contributes in many ways to increase productivity. This is due to the change of concept, since traditional management focuses mainly on reducing the time of activities, while the LC focuses on the establishment of the flow, reducing interruptions.

Although the Lean concept isn't new for the construction industry, since the first publications go back to 1992, the (low) number of publications found, they reflect the possibility that this system is not yet widely used in this sector.

However, one of the limitations of this research refers to the SLR search criteria, since only English-language journals and Journal articles were considered. But, it's possible there may be more works available in conferences or other languages.

Another limitation of this work refers to the calculation of the production function, since this presupposes that the technology used by the sample companies is the same, however, it was not possible to guarantee this aspect. Despite this, for purposes of illustration, calculating the productivity of the global construction industry has reached its target.

Even if there are many other studies of productivity, the innovative character of this article lies in the referral of lean construction as a necessary alternative for the construction industry.

For the future work, as in the automotive industry, it is important to develop a function capable of incorporating a Lean Construction proxy, able to show, based on the result of empirical studies, the productivity increase of the builders who adopted the Lean model.

Another important point to be developed, it is to expand the analysis to conference papers, in order to estimate the level of Lean Construction expansion.

It is worth mentioning, that the increase in LC expansion will not only bring benefits to construction companies, but also to an audience that still needs housing, basic sanitation and other infrastructure works in general. From the moment these projects are executed more efficiently, this population may have its needs met in terms of both the volume of works and the reduction of the costs of executing them.

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