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Impacts of the Application of Lean Construction to Reduce the Generation of Waste and Improve Processes in Construction

T. M. Viana[1], P. V. Salles[2], C. C. Carvalho[3], B. L. S. S. Teixeira[4], M. A. Moraes[5], W. J. Santos[6]
[1,2]Postgraduate Dept. in Civil Engg., Federal Center of Technological Education of Minas Gerais, Belo Horizonte - MG, Brazil
[3,4,5,6]Federal University of Minas Gerais, Belo Horizonte (MG), Brazil
([1]thiago.m.viana@hotmail.com, [2]pedrovallesalles025@gmail.com, [6]white.santos@demc.com.br)

***Abstract*-**Considering that the macro-sector of construction produces goods of larger physical dimensions and, therefore, is one of the biggest consumers of natural resources, this paper is about the implementation of lean construction techniques in a construction work to reduce waste generation and improve the efficiency of the construction processes. The purpose of this study is to analyze benefits of applying concepts of Lean Construction in civil construction works. The research method consists in a case study, in which the construction site adopted the principles of Lean Construction. In this work it was found that the implementation of this concept promoted a significant reduction (27%) of waste generation. Furthermore it provided a reduction in the final cost of the project and increased the efficiency of processes. The proposed methodology can be applied on construction sites without burdening the budget and propitiates financial and social gains with a considerable decrease in the impact of construction into the environment.

***Keywords*-** *Lean Construction, Generation of Waste in Construction, Efficiency of Construction Processes*

I. INTRODUCTION

The construction industry is essential to the growth of a nation and a key sector in the nation's economy. The growth of a country is linked to construction of infrastructure necessary for development. The contributions of this important sector in the process of development goes beyond economic aspects; roads, dams and irrigation work, schools, houses, hospitals, airports, railways and other construction works substantially contribute to the maintenance of wealth and quality of life of the population [5].

No other industry in the United States uses more material by weight than the construction industry. Because of its economic and social importance, it is also a major polluter, and consequently a frequent target of criticism. The population has strengthened its control over the environmental impacts of the construction activities [4].

According to Miranda [8], about 0,52 tons of construction waste is generated in Brazil per inhabitant per year or 150 kg per square meter built (for new construction works), representing 55% to 70% of the total municipal solid waste. According to Costa [2], there are several reasons for those alarming numbers of quantities of waste: artisanal services, unqualified labor force, technological gap, workforce turnover, losses in the production process. Additionally there is accommodation of the entrepreneurs of the sector, in the sense of not seeking for new technologies and construction techniques in order to reduce the generation of waste. If the waste is not treated and properly disposed, it can cause serious environmental damages, such as the aggravation of urban floods, visual pollution, diseases proliferation and increasing costs of municipal administration.

The environmental impact of construction occurs in the entire production chain, since the conception of buildings until their demolition. Because of this situation, several initiatives have been made to enable technically and economically the recycling of municipal solid waste, such as the development of research in universities [13], the standardization of recycled aggregates, the CONAMA Resolution 307/2002 and the public-sector support. This is increasing the recycling of waste in Brazil, through the installation of public and private recycling plants.

In this problematic context of civil construction, in the search for improvement in the production and planning system for civil construction, Lean Construction emerged, [14]. According to Koskela [15], while the traditional concepts of the construction production system have a single final goal, product delivery, in turn lean construction has its concepts focused on three main objectives: product delivery, Value and reduction of waste.

According to Koskela [9], the model called Lean Construction consists in a flow of materials, from the raw material to the final product, and is composed of transporting, waiting, processing and inspection activities. The activities of transport, waiting and inspection are considered flow activities because they do not add value to the final product. Also it is worth mentioning that not all processing activity adds value to the product. As an example there is the case in which there is no detail to perform a particular service and, because of it, the service is not performed as desired. Then there is a need for rework, which means that the processing activity was performed without adding value.

According to Isatto & Formoso [6], the process of Lean Construction is characterized by the generation of value;

therefore, a process only creates value when processing activities that transform raw materials or components into the products. In the case of managing processes, instead of materials, there are the transportation, waiting, processing and inspection of information. There is another type of flow that needs to be controlled, the work flow, which refers to the set of operations performed by teams or machines on the construction site.

Picchi [12] says that the competitive and continuous improvement of enterprises through the elimination of waste and the constant attention to the requirements of customers in variety, quality, time and price are some of the goals of lean thinking. Eleven principles of lean construction were developed, in order to cover the points that must be polished, providing the successful implementation of the system. In civil construction, performance measurement is very important to the industry and to the academic community, it is an essential element for the management of enterprises [16]. The performance of the application of these principles will be analyzed later in this study.

This work had as purpose the analysis of the reduction of waste generation in a construction site through the adoption of Lean Construction. The specific aims of this work are:

- Analysis of the application of the eleven principles of Lean Construction presented by Koskela [9] in the work object of the case study.
- Evaluate some reflections of the application of these concepts on environmental and financial gains

II. METHODOLOGY

A. *Analysis of the practical application of the principles of Lean Construction*

At first, this study analyses the practical application of the eleven principles presented by Koskela [9] to implement the philosophy Lean Construction, which are shown below:

- Reduce the share of non-value-adding activities;
- Increase output value through systematic consideration of customer requirements
- Reduce variability;
- Reduce cycle times;
- Simplify by minimizing the number of steps, parts and linkages;
- Increase output flexibility;
- Increase process transparency;
- Focus control on the complete process;
- Build continuous improvement into the process;
- Balance flow improvement with conversion improvement;
- Benchmark.

B. *Calculation of benefits*

Thereafter, this study carried out a comparative analysis between the case study and literature data to understand some benefits of application of Lean Construction. Four aspects were raised as a sample to the benefits of methodology application. This process can be summarized as follows:

- Comparing the actual volume of waste generated on site with the theoretical value obtained by the technical literature values to measure the reduction on waste generation;
- Calculation of the savings from the reduction of buckets rental, as a way of measuring a financial gain by reducing the volume of waste generation;
- Calculation of the savings from the reduction of the purchase of bricks, as a way of measuring an example of financial gain with the reduction of loss of materials used in the work ;
- Calculation of the savings from the reduction of deployment and demobilization of the administrative structure in the layout of the construction site, as a way of measuring a financial gain by reducing this activity.

III. CASE ESTUDY

The case study has as object a construction work of a company which operates in many Brazilian states, in the residential, commercial and ground set sectors. This work is composed of several residential towers that, when concluded, will have more than six hundred apartments, totalizing a built area of 121.302,20 m^2. This work was chosen because it initiated the process of implementation of a quality management system and the principles of Lean Construction simultaneously with the mobilization of the construction site. Figure 1 shows a perspective of the enterprise.

Figure 1. Perspective os the enterprise

Below it is presented the analysis of each of the principles of Lean Construction presented by Koskela [9] applied in this construction work, looking for its benefits in reducing time, costs and waste generation.

A. Analysis of the application of the principles of Lean Construction

1) Reduce the share of non-value-adding activities

The non-value-adding activities are present in almost every process and are those that demand time and costs; however, they do not contribute to the generation of value in the final product. The movement, waiting and verification are activities that must be reduced and, if possible, eliminated, because they are considered waste within the production process.

The analysis of the activities is essential, because some of them, despite not adding value directly to the final product, contribute to the efficiency of some processes, such as the work safety and work planning. After a global analysis of construction processes, the points where the losses were occurring were defined. The possibility of redefine the process to a more efficient sequence was considered and the existence of problems in the construction site layout planning as well as in the material transportation system were analyzed.

In order to reduce the non-value-adding activities it was necessary to take the following steps: analysis of the construction site layout and use of the design process tool. The first is based on the condition that the work would be delivered in several phases. A study was conducted to decide the location of the facilities in the construction site, and the sectors of engineering, administration, work safety and infirmary, which were necessary at all stages, were implanted so it that would not be necessary to change its physical location along the delivery of each phase. This procedure was responsible for reducing the costs associated with changing facilities at construction site and reduction of waste generated by such changes.

The second action emerged with the development of the design process tool, complementing the PIS (procedure to implement the service) and the RCS (record for checking service). The tool is connected to the planning of the activity and gathers important information to a good running of the service, enabling the correct movement of materials, avoiding surpluses and losses and, consequently, reducing waste.

2) Increase output value through systematic consideration of customer requirement

During the production process, there are the final customer and the customer that performs the next activity in the production chain. By mapping the flow, the customer can be identified at each stage of the process to the evaluation and fulfilment of his needs.

To add value to the product, the following procedure was adopted: the services are checked and released by completing the RCS (record for checking service). If any pending is found, the contractor has a deadline to correct it and deliver the floor clean, besides being prevented to start the service on another floor. Thus, the next service (new internal customer) has the guarantee that the previous phases have been completed correctly. This action was very important in enabling a control of materials and reducing material waste, since the contractor will select the materials that still can be used for the execution of the service in another floor while delivering the floor clean.

3) Reduce variability

Throughout the production process several variables are found, such as the processing time, dimensions of the materials to be used and the flow (arrival of tasks at construction site). The reduction in variability can be obtained through the standardization of processes to decrease the number of activities that do not add value.

In the studied construction work, in order to reduce variability, it was adopted the use of modulated masonry, aiming the standardization, agility and reduction of losses in the execution process. The electrical installations are implanted in u-blocks, the hoses are inserted into the blocks throughout the execution of masonry, eliminating cuts, and the electrical boxes are embedded in the blocks before the execution of masonry.

As a result of adopting this principle it was possible to improve the management of materials, equipment and control of the processes for a continue flow of work, continuously reviewing the activities plans and avoiding interruptions of tasks.

4) Reduce cycle times

The cycle time is calculated by summing the time spent over the entire production process. It is the sum the times of the processing of inspection, waiting and handling. The reduction of the cycle time generates an increase of productivity, eliminates the waste, allows the anticipation of delivering the product to the customer and assists the management of processes. Aiming to reduce cycle time was performed:

- Critical analysis of projects: It was evaluated if some proposed coating were appropriate for the time available and it was performed the replacement of the cladding filleted in stone for ready stone plate. This reduced the cycle time, because handling the ready plate is easier than handling the cladding filleted in stone, as shows Figure 2.

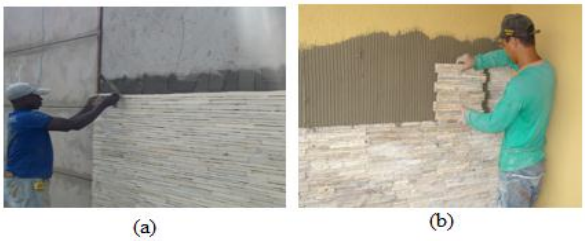

Figure 2. Application of stone (a) filleted, (b) ready stone plate.

- Adoption of projects with floors and walls modulated: the area to be clad must have dimensions compatibles with the cladding used, reducing the time to settle and the generation of waste, since it prevents or eliminate the indentations in cladding pieces.
- Use of precast slabs: at the implementation phase, the use of this material was responsible for providing great agility for the construction work and reduced a lot the

consumption of wood. The wood is normally used to produce the formworks of the slabs, and the reduction of its consumption reduced the generation of waste.

5) Simplify by minimizing the number of steps, parts and linkages

A process can be simplified by reducing the number of products components, reducing the number of parts or steps, eliminating activities that do not add value and reconfiguring the steps and stages that add value. The use of industrial elements and the effective planning also contribute with the simplification.

As higher be the number of steps in a process or parts, greater is the tendency that there are non-value added activities [7]. This simplification can be achieved through the utilization of pre-molded elements, multi specialized teams and mainly with effective planning of production methods. For particularities of the work and of the quality system implementation phase, it became only the study of the layout and the redefinition of some activities within the construction site.

6) Increase output fexibility

The flexibility increase was achieved through the reduction of the size of the batches, through the possibility to customize the product as late as possible and through the implementation of construction processes that allow the modification of the product without generating a significant cost increase.

Another action adopted was the labor force training to perform different tasks, enabling adaptations. This training had the objective of directing the workers of civil engineering industry to a new professional attitude, in which they assume more responsibility for the quality of the developed product, as well as for the final performance of the contractor.

Aiming the application of continuous improvement, the employees were motivated to work towards identifying problems, and, thus, they could eliminate the causes of the failures. Through twice a month meetings on the principles of the methodology, they searched to develop skills and lean knowledge for solving problems in real cases and suggest alternative solutions for improving construction processes.

7) Increase process transparency

The transparency facilitates the production control, allowing the identification of problems in the process, reducing the occurrence of possible errors and facilitating the work. As discussed by Isatto [7], it is possible to increase the process transparency implementing a communication system with the use of visual devices (warnings and signalization), disseminating performance indicators, removing visual obstacles (partitions and sidings) and keeping the construction site clean.

The good organization was responsible for avoiding systematic waste in the utilization and acquisition of replacement materials and also reduced the occurrence of accidents. The undertaking administration walked around the construction trying to locate leftover materials to avoid the problem of them disposed as waste. When the administration located these possible leftovers (mortar bags with part of the initial content, some blocks that were not used, clippings hoses of electrical installations with enough size to reuse, etc.), they collected and stored them, so they could be used in other processes. This practice has reduced the amount of waste generated and optimized the use of labor force, since there was no need to transport the waste to storing.

8) Focus control on the complete process

The careful control of deadlines and cost provides, through its analysis, the taking of actions aiming the correction of possible deviations. Through the adoption of a systemic view, it was possible to improve the quality system, increase the efficiency of the production process, strategically redirect the enterprise's resources and improve the quality of life of the workers involved by providing benefits.

The system initially used to control the activities in the construction work was fairly generic, because when an indicator was changed, it was not possible to identify the cause, but it has changed with the lean construction methodology. An example can be the class of costs of labor, which includes a great number of services. If one person has been hired out of the budget, that person would immediately affect the outcome of the class. Another item carefully controlled was the purchase and storage of construction materials. To make it possible, the storekeeper of the construction was responsible for keeping the stock of materials as organized as possible and accounts every material that was removed from the stock. Thereby, there was a large reduction with material costs and generation of waste in the construction, due to the correct storage of materials, which prevent damages and ensured the conditions of usage.

9) Build continuous improvement into the process

Perform continuous and in steps improvement into the process is very important to the successful use of lean concepts [9]. The benefits generated through the continuous improvement provide competitive advantages relative to companies. The continuous improvement requires the involvement of the employees: developing the teamwork, setting goals, the constant search for better ways of doing the job. The continuous improvement can be inserted on the process through the systemic training in support of organizational improvement, aiming to ensure not only a product that meet the legal and regulatory requirements applied to the sector, but also the quality of the constructive process, in order to rationalize the usage of materials, labor, equipment and mainly the occurrence of waste. This continuous improvement was achieved with the promotion of training courses and training of the employees of the construction site, encouraging reuse and reduction of waste materials, the identification of sources of loss and the proposition of possible changes in the adopted construction process, aiming to extinguish these sources of loss.

10) Balance flow improvement with conversion improvement

According to Koskela [9], the flow improvement is interconnected with conversion improvement in the following way:

- Improved flows require less capacity of conversion

- More controlled flows facilitate the implementation of new technologies in the conversion
- New technologies of conversion can minimize variability, benefiting flows
- The flow improvement must be searched before seeking conversion improvement

The layout study and its readjustment to improve the flow of activities can be mentioned again to exemplify the flow improvement in the construction.

11) Benchmark

Through a research, is made a comparison between the current performance of the enterprise and the performance of competitors, taking into account the processes, products and business practices. From the knowledge obtained, a selection of best practices is performed for posterior adaption and implementation, generating processes improvement. Benchmarking is a process of learning from references of other companies considered as "leaders" in certain aspects or segments [7]. As the undertaking in question is still starting on this thought, we can affirm that the adoption of Lean Construction is already a Benchmark, although other actions will be implemented after stabilization of the adopted methodology.

B. Calculation of benefits

1) Comparing the actual volume of waste generated on site with the theoretical value

To analyze the efficiency of the application of lean construction methodology, a comparison was performed, in environmental and economic parameters, of the amount of waste generated by constructions that have not adopted the Lean Construction methodology, obtained with the literature for a hypothetical situation, and the actual situation of the case study, in which the methodology was applied. To the hypothetical situation the following data were considered:

- Total built area: 121.302,20 m2 (according to the case study);
- Generation of waste per unit of area: 150 kg/m2 [10],[11],[3], [1];
- Density of the waste: 1,28 ton/m3 [10],[11], [3], [1];
- Volume of one bucket of rubble: 5 m3

From this data, it was possible to calculate the hypothetical amount of waste that would be generated at the construction site, totaling an anticipated volume of 14.215,10 m3 of waste, or 2.884 bucket of rubble. Actual data obtained with the administration of the construction site show that 2.077 bucket of rubble were used during the construction, showing the great effect of the adoption of the principles of Lean Construction methodology. They used 767 bucket of rubble less than planned which represents a reduction of 27%, compared with the number estimated for the hypothetical situation, which shows great environmental gain.

2) Calculation of the savings from the reduction of buckets rental

Consequently, the adoption of Lean Construction principles was also responsible for the reduction of outgoings related to the rental of bucket of rubble and purchase of materials. With regard to the spent with bucket of rubble, the engineer responsible for the sector of planning and control of the construction informed that it was paid, in average, R$240,00 per rented skip, thus the economy of bucket of rubble propitiated an economy of R$184.080,00, once 767 buckets were no longer rented because of the actions implemented.

Considering the hypothetical situation previously raised, the economy in the cost of renting buckets is approximately 26% (R$184.080,00), a significant value in the cost of the work, that is, there is a considerable financial gain here in the application of Lean Construction principles.

3) Calculation of the savings from the reduction of the purchase of bricks

Due to proper storage and the bigger control of the stock, a reduction in the consumption of various materials was observed. The decrease of the planned spending with the purchase of bricks has received much prominence, as shown in Table 1.

TABLE I. PLANNED AND REAL SPENT FOR THE PURCHASE OF CERAMIC BRICKS.

Material	Planned spent (R$)	Real spent (R$)	Value saved (R$)	Percentage saved (%)
1) Ceramic Brick 9X19X29	120.354,93	90.266,20	30.088,73	~ 25%
2) Ceramic Brick 14X19X29	229.871,88	172.403,91	57.467,97	~ 25%
3) Ceramic Brick 19X19X29	57.188,75	41.175,90	16.012,85	~ 28%
Total	407.415,56	303.846,01	103.569,55	~26%

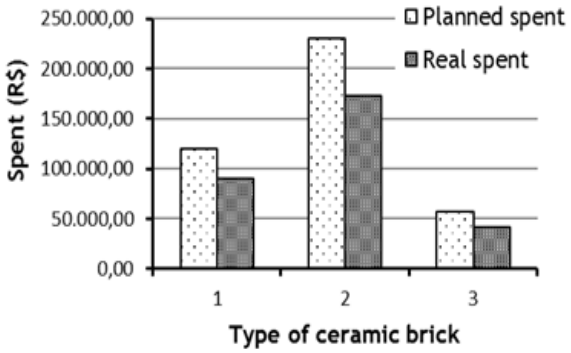

Figure 3. Comparative graphic between planned and real spent with purchase of ceramic bricks.

Figure 3 shows a comparative graphic with the situation above.

According to table 1 and figure 3, it can be seen that the principles of lean construction were solved for a further financial gain, in the order of R$103,569.55, that is, 26% of the budgeted amount for the acquisition of ceramic bricks. This shows a good example of how this methodology can be positive in the economy in material consumption.

4) Calculation of the savings from the reduction of deployment and demobilization of the administrative structure in the layout of the construction site

Another great saving was due to the construction site layout study, since the cost with each implantation and demobilization of the administrative structure and support areas (living area, warehouse, refectory) is about R$73.000,00. With the layout study of the construction site, considering the various stages of delivery, the total saving associated with the mobilization of these structures informed by the project administration was of R$ 255.500,00. By reducing an activity that does not generate value, once again, there is considerable financial gain in the application of the Lean Construction principles, since the amount saved is quite substantial in the budgeted global value.

IV. CONCLUSIONS

The Construction Industry, due to its particular characteristics about the production process and considering its dimension when it is analyzed the consumption of natural resources, is responsible for great part of the waste generation. Given this scenario and the growing importance of sustainable development, it has been currently observed an emphasis on the discussion of ways to reduce the unnecessary consumption of materials and the generation of waste in construction.

Every participant involved in any phase that compose a constructive process is responsible for preventing and reducing the generation of waste to avoid future environmental problems. Brazil has been evolved greatly the issue of waste management, but is still delayed compared to European countries. It is necessary to carry out studies that validate the implementation of philosophies that aim to reduce the volume of waste generated in works.

In addition to the environmental issue, it can be seen that reducing costs and improving the efficiency of construction processes are a concern both for the technical environment and for business owners and investors. The aspects analyzed in this work regarding the effects of the application of the concept lean thinking, although representing a sample within the complexity of the work, indicate the great potential of optimization of the constructive processes of this philosophy.

In this study it was observed that the application of Lean Construction principles at each stage of construction, in other words, in the phases of design, construction site mobilization, execution and finishing, was responsible for a significant reduction of waste generation and in the costs of the undertaking, through rationalization and improvement in processes.

In addition to the reduction in the volume of waste generated, it was possible to measure gains with savings in the purchase of materials, in expenses with buckets and with the mobilization of construction sites. This perception of the gains in several aspects is important to help in the diffusion of the Lean Construction's philosophy, once is possible to notice in the case study that the proposed methodology can be applied on construction sites without burdening the budget and also propitiate financial and social gains.

Finally, it is concluded, even with numerical proof, that the philosophy lean construction has many advantages, in the environmental and economic aspects. It is necessary that studies be developed to further explain the benefits of applying the principles of this methodology. In addition, it is necessary to promote a culture change in which the search for the most efficient and more sustainable is a priority in the development of enterprises.

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T. M. Viana has a degree in Civil Engineering from the School of Engineering of Federal University of Minas Gerais (UFMG - 2015), Technician in Transport and Traffic at Federal Center of Technological Education of Minas Gerais (CEFET- MG – 2009) and a Master's degree student in civil construction, at Federal Center of Technological Education of Minas Gerais (CEFET- MG -beginning in 2017).

P. V. Salles has a degree in Civil Engineering from the School of Engineering of Minas Gerais, Federal University of Minas Gerais, Minas Gerais, Brazil (UFMG - 2015) and a Master's degree student in civil construction, at Federal Center of Technological Education of Minas Gerais (CEFET- MG -beginning in 2016).

W. J. Santos has a degree in Civil Engineering from the College of Engineering of Juiz de Fora Federal University, Juiz de Fora, Minas Gerais, Brazil (UFJF - 2009), graduate studies in Work Safety Engineering (UFJF - 2010), a Master's degree in constructed environments (UFJF - 2011) and a PhD in Civil Engineering (UFV - 2014). He is an Assistant Professor, Department of Materials Engineering and Construction (UFMG - 2012), works with research related to Sustainability, Wastes, Building Materials, Construction Processes, Maintenance/Pathology, Construction Management and alternative materials.