LEAN CONSTRUCTION IN REHABILITATION WORKS – SUITABILITY ANALYSIS AND CONTRIBUTION FOR THE DEFINITION OF AN APPLICATION MODEL

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ABSTRACT

In recent years, the construction industry in Portugal has been waking up to the paradigm of Lean Construction. This is due, in part, to the strong global economic crisis and the consequent need to increase the competitiveness of enterprises.

The aim of this paper is to assess the applicability of the Lean Construction techniques in rehabilitation works, as well as to contribute to the definition of a corresponding application model.

This article reports the application of Lean Construction techniques in a rehabilitation project, having used the methodology of document analysis, direct visualization of processes, development of Value Stream Mapping (VSM) of the target processes and implementation and review of proposals for improvement. Finally, interviews were conducted on key elements of senior management of the company in order to evaluate the receptivity to the proposed changes and their generalization potential to the whole of the rehabilitation works of the company.

It was concluded that it is possible and beneficial to implement Lean techniques in rehabilitation works. It was noticed that some of the good practices implemented on site closely matched or even completely materialized Lean techniques, such as Just in Time (JIT), the 5S, Kanban and Last Planner. However, and having in mind the Lean philosophy of continuous improvement (kaizen), it was still possible to formulate proposals for improvement to processes not yet fully optimized.

KEY WORDS

Lean Construction, Rehabilitation, Value Stream Mapping, Waste Disposal, Continuous Flow.

INTRODUCTION

The Construction Sector presents itself as a major driver of economies in many countries. Across Europe, Building Rehabilitation represents a significant percentage of turnovers in the construction sector.

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According to a report by AECOPS (Portuguese Association of Companies of Construction and Public Works) in 2009, rehabilitation works will have a very strong growth, representing an estimate of about 45% of the production value of the construction industry in Portugal in 2030. (Afonso, 2009)

Alongside this, given the current global economic crisis, companies are forced to deal with ever tighter profit margins, making it crucial to reduce costs in order to remain competitive.

This study aims at analyzing the existing waste in rehabilitation works and how Lean Construction can be applied in order to eliminate it, adding value to the end product.

The case study portrayed was conducted at a job site from a Portuguese construction company with works in four continents; therefore it is of great interest to study the work in question since the optimizations achieved can be spread worldwide.

Thus, the research question of this study is: "What is the suitability of Lean Construction in rehabilitation works and how should the model for its application be?"

Initially, a literature review was conducted on Lean principles and key issues in rehabilitation works. A methodology was then defined for data collection and a present state determined. Then, the proposed changes, based on Lean principles, were implemented, an analysis and discussion of results was made and conclusions were drawn.

The results indicate that the use of tools such as *Percent Plan Complete (PPC*) and Maps of Irregularities, as well as the use of two subcontractors for the same process are capital gains to avoid delays and frequent errors.

LITERATURE REVIEW

The term “rehabilitation” or “renovation” in the context of buildings articulates the purpose of recovery of pre-existing values in an ancient building, possibly with historical value, with the overall improvement of its characteristics through the adjustment to the needs and demands of contemporary use, avoiding the loss of their essential aesthetics, historical, architectural and urban value (Paiva et al. 2006).

This creates specific challenges that need to be met. Some of the most important are:

• The location and geometry of the buildings to be intervened –these are generally ancient structures in old urban areas with inadequate accessibilities to present day construction machinery, and have serious limitations in the size and functionality of the staging and work area;

• High levels of variability due to unknowns, caused by incomplete knowledge about the original construction, its present state of decay and unrecorded changes to the original building over the years.

Construction industry is characterized by its non-stationary nature. Its production is carried out in ever changing locations, and its work teams, equipment, fringe conditions and interfaces are always different (Bubshait and Al-Atiq 1999). Still, new projects allow for a certain level of standardization. The stakeholders may choose the materials, equipment and technical solutions to be utilized. This is not the case in rehabilitation works, where they must adapt to the uniqueness of the intervened object

and adjust to its specifics, be it the construction method, the equipment or the materials to be used. This causes an extra challenge to attempts of standardization, creating a continuous workflow and managing resources, procurement and logistics. Often the full knowledge of the materials to be utilized is only achieved during the production process itself.

Increased safety risks also arise from these conditions, since unknowns make planning and prevention more difficult.

Still, the market of rehabilitation works cannot be neglected. In a survey by the European Federation of the Construction Industry (FIEC), cited by Afonso et al. (2009), it is indicated that its weight in the overall construction revenues amounts to 32% in Germany, 29% in Italy and 26% in Finland. These figures tend to rise in the old economies of the most industrialized countries.

LEAN SOLUTIONS

For decades, the construction industry has been looking to the manufacturing industry in search of solutions to minimize its problems. The industrialization (pre-production and modulation), computerized integration and automation are examples of that (Koskela, 1992). Therefore, it is not too surprising that the Lean management system was imported from manufacturing, evolving, since its appearance about two decades ago, with its own identity. It followed a particular path, which currently does not have a unanimous definition but, like other industries using Lean ideas, seeks to improve productivity and to achieve a strong economic performance, increasing simultaneously customer value and profit for the company.

To eliminate waste it is necessary to better understand and characterize it. Taiichi Ohno the founder of Toyota Production System (TPS) identified seven types of waste (Ohno, 1988), which are common to the construction industry, and are designated by Muda:

- Overlay - relates to the manufacture of a product before it is needed or in amounts greater than the request;
- Waiting – for material, equipment or labor;
- Transport - refers to the unnecessary transport of materials or products. In addition, movement of workers increases safety concerns and problems;
- Excessive movement - refers to excessive movement of workers or equipment to camouflage inefficiency. It is intimately connected with the poor organization of the workspace;
- Process that does not add value - every work of reprocessing, storage or repair;
- Excess stock - the stock should not exceed what is necessary to fulfill the process or consumer demands.
- Defects - resulting from execution errors or ineffective tasks;

Later, Koskela and Bertelsen (2004) suggest a new waste not identified by Muda, referred to as "making-do". This waste is related to the fact that the activities are initiated without guaranteeing means and resources needed to implement them, thereby causing interruptions in the flow of activity.

Over the years, several concepts and tools have been developed or became associated to Lean, and specifically to Lean Construction. Considering the characteristics of rehabilitation works previously described in this article, some Lean solutions appear to be particularly indicated to meet their challenges.

5S

Considering the lack of space is common in rehabilitation works, the number of different trades and teams working simultaneously, the significant amount of debris resulting from frequent demolition works, the difficulty of access to the staging and work areas, the 5S process presents itself as a useful working tool.

It is based on five principles aimed at the organization and standardization of space. Those five principles are:

• Seiri (sense of use): Refers to the practice of checking all the tools and materials in the workplace, removing all those that are not required to perform the task at hand;

• Seiton (sense of organization): refers to the need for an organized work space. All tools, equipment and materials should be identified and organized around the place where the task will be performed;

• Seiso (sense of cleanliness) - the focus of this procedure is to make cleaning an integral part of daily activity and not an occasional activity;

• Seiketsu (sense of standardization) - Refers to standardization of work practices and organization of space, respecting the rules established earlier.

• Shitsuke (Sense of self-discipline) - once the four previous rules were implemented, these should be seen as a new way of working. The steps above should be repeated, in pursuit of continuous improvement.

Lean Planning

As indicated above, rehabilitation works are characterized by unknowns. Often work quantities and their nature are determined on site, as work progresses. This creates an environment where “push” planning is set to fail. The best fitted players to determine which works can be effectively executed are those who find out, on a daily basis, which works need to be done and can be done. The major pull planning system in Lean Construction is the Last Planner System™ (LPS).

Created in 1992 by Glenn Ballard, the LPS™ is one of the most common applications of Lean Construction. It is a toolkit that allows control of short and medium term planning, in a "pull” system, thereby ensuring that all the prerequisites for the start of the activities are completed before they start.

An important part of LPS™ is the Percent Plan Complete (PPC): This is an indicator that reflects the ratio between the number of activities actually performed and the number of planned activities. Usually expressed as a percentage, it allows checking the compliance with the proposed “pull” plan (Ballard 1994).

Logistics and Management of Stocks

Scarcity of space and difficulties in the access to the staging and work areas demand a careful management of logistics and stocks. In rehabilitation works it is not uncommon that the access of equipment and materials to the various site areas

requires the utilization of special equipment or procedures. In this context, the Just-In-Time (JIT) concept presents itself as a promising solution: As one of the main pillars of TPS, JIT has as its main function to regulate the supply of materials by the supply chain, supplying them in the right quantity, at the right time and resulting in drastic reduction in stocks (Vrijhoef and Koskela, 2000).

Process Analysis and Optimization Tools

Value stream mapping (VSM) is a tool that can be used to look at a process to reduce or eliminate waste in that process (Mastroianni and Abdelhamid 2003). It is a visualization tool often used in any kind of Lean implementation, aiming at eliminating tasks that do not add value to the production system. VSM is based on an evolutionary process that consists of five main phases: Choice of procedure; Mapping of the current state of the value stream; Analysis and proposals to increase efficiency; Mapping of the future state of the value stream; Implementation of the changes and check (Abdulmalek and Rajgopal, 2007). It is fundamental in process analysis and optimization applied to case studies, within the framework of Lean Construction.

RESEARCH METHOD

This study aims to test the applicability of selected Lean solutions in rehabilitation works. To this end, a partnership was established with a company in the construction sector in Portugal, Soares da Costa Construções S.A., with the aim of collecting data from a case study and determining the benefits obtained. Finally, the generalization of these results was analyzed and discussed.

The data and information gathering was based on four processes:

- Document analysis;
- Direct observation;
- Meetings on site;
- Interviews with senior staff of the production department for validation of the model obtained and assessment of its generalization potential.

The first three points allowed the characterization of the works, the perception of their overall functioning, as well as the observation of various types of work taking place simultaneously. The last point allowed to investigate whether or not the data collected on site represented the company's common practices, and also to explore the interest by top managers in implementing the measures proposed in other works of the company.

After studying the Lean concepts and understanding the general functioning of the works observed, and in order to test the applicability of Lean concepts in rehabilitation works, a model for practical application was drawn. This model was developed according to the information gathered through the utilization of VSM. The development of the proposed model comprises five steps:

- Observation and choice of the procedure subject to the implementation of improvements;
- Elaboration of a current value stream map;

• Analysis of current VSM and presentation of proposals in order to improve the efficiency of the process;

• Elaboration of a future state value stream map;

• Implementation and assessment of the results.

ANALYSIS AND DISCUSSION OF RESULTS

Upon completion of the future state value stream map, two production processes were selected for implementation: gypsum wallboards and formwork. This selection was based on process relevance in terms of quantity of work and financial value involved.

At this stage, the authors realized that, while some production processes could be optimized, this job showed evidence of optimization efforts. Although the site management staff reported not having any knowledge of Lean principles and solutions, several production steps had optimized processes that did not correspond to common practice in the Industry. Common sense, experience and interest in optimization had led the site management to implement measures in this job that were in line with Lean solutions. Table 1 below portrays those processes in the Gypsum wallboards' works and establishes the correspondence with the respective Lean solutions.

GYPSUM WALLBOARDS PROCESS

Table 1 depicts the production steps in the gypsum wallboards process, which was found to be optimized.

Table 1: Optimization of the gypsum wallboards process

Gypsum wallboards		
Step	**Optimization**	**Lean Designation**
Order/reception of the material	Ordering material just one day in advance; Stock of material on site for just one week of work	JIT
Displacement of the material	Upon delivery of the material on site, it is automatically forwarded to the respective work fronts	*Muda* e 5S
Waste collection	Throughout the application process, wastes are being forwarded to the appropriate container	5S
Waste disposal	When the container is full, disposal must take place within a day	5S

Regarding the management of stocks, it was found that care had been placed in reducing the size of stocks, tending to a JIT approach. In this job the material was ordered on a one day notice and its stock on site was enough for a week's work. Considering that the common practice in this company and in the industry consists of having stocks for three week's work, this allowed a reduction of the space required in

the staging area by 67%. This was confirmed later on, in the interviews stage. It was also found out that these works tended to be more and more subcontracted by the company, which was the case in this job, where the respective subcontractor was responsible for the supply and stock management.

Concerning the movement of material, it was observed that the material was forwarded directly to the work fronts, improving not only the previous step but also reducing storage space by almost 100%. Another fundamental benefit was the reduction of the crane usage. Due to the site's geometry, access conditions and scarcity of space, the site's tower crane played a vital role in the delivery of materials and in the production process, and the optimization of its usage had paramount importance. The adoption of this measure allowed direct gains resulting from the reduction of the crane usage of an estimated 26.5€/hour, for each delivery of material. This practice, which followed the principles of 5S and eliminates the waste of Muda, was not considered common practice in the company.

Regarding the immediate disposal of waste to the appropriate location, this activity was already in practice, promoting the organization and cleanliness of the workplace, principles defined in Lean's 5S. This allowed resuming work immediately the next day and a clear separation between waste and material suitable for applying. It was concluded that this procedure was common practice in this subcontractor's works. The removal of waste from site was also considered optimized in the light of these principles, as it is carried out within a day after this service is requested.

FORMWORK MATERIAL PROCESS

After completion of the VSM for this production process, as shown in Figure 1, it was found that, contrary to the production process of the gypsum wallboard, the formwork material process had room for optimization.

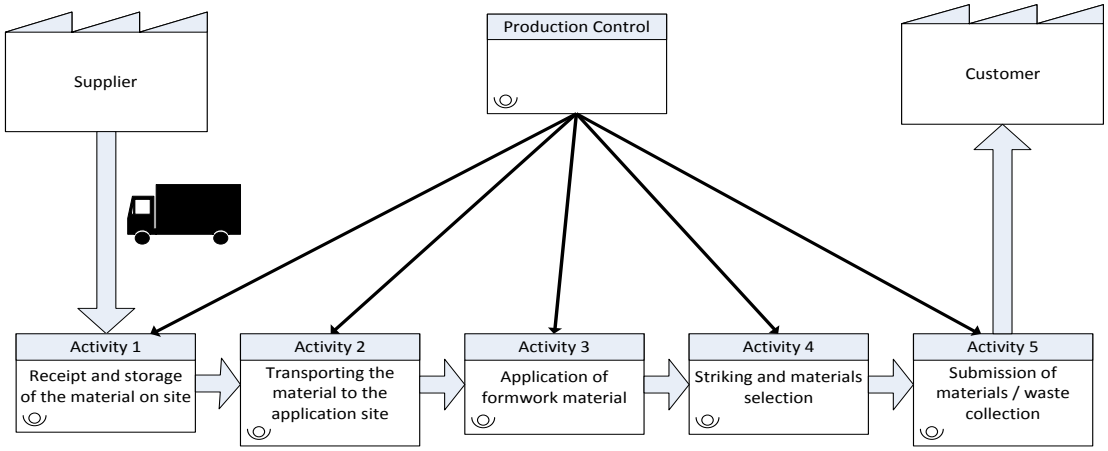

Figure 1: Formwork - Current Value Stream Mapping

Table 2 below depicts the proposed improvement to the process of stripping formwork material and Figure 2 the VSM of its future state.

The practical implementation of this proposal was carried out during the stripping of the beams covering the core of one of the buildings, and in one of its concrete

walls, comprising a total area of 128 m2 of formwork to be removed. Four workers, three carpenters and one laborer were assigned to these works.

This measure failed to reduce the duration of this activity, which was completed in 8 hours. This was due to the fact that the duration of this activity was constrained by the crane. This equipment was required for the disassembly and displacement of the formwork panels from that work front to the next, and was being simultaneously required to perform other activities. Thus it could not be used as foreseen in the VSM of the future state portrayed in Figure 2 below.

The measure described in table 2 was found to produce quite positive results, since it enabled the site to be totally clean and clear by the end of the day of the activity, without the need for an increase in resources and avoiding the use of the crane later. This reduces the cost of the activity in terms of manpower and equipment in about 1/5.

Table 2: Proposed improvements to the Formwork process

Formwork Material		
Improvement Proposal	**Benefits**	***Lean* Designation**
When placing and removing formwork, immediately proceed to the clean up the site from waste, using containers placed in the close vicinity	Enables a clean, easy to read site (perceived barriers); Allows start prompt start of the works downstream; Increases the safety at work and waste collection and disposal is faster	5S

There were no extra costs associated with this change, since the equipment and manpower used to carry out the activity are the same that were used before the activity was improved.

According to those responsible for the activity, it could have been completed in 5 hours if it had not been constrained by the crane. It was concluded that the implementation made optimized the utilization of the manpower and the use of the crane, which is often a significant constraint in rehabilitation works. The contractor considered this measure positive, and its generalization to other works of the company welcomed.

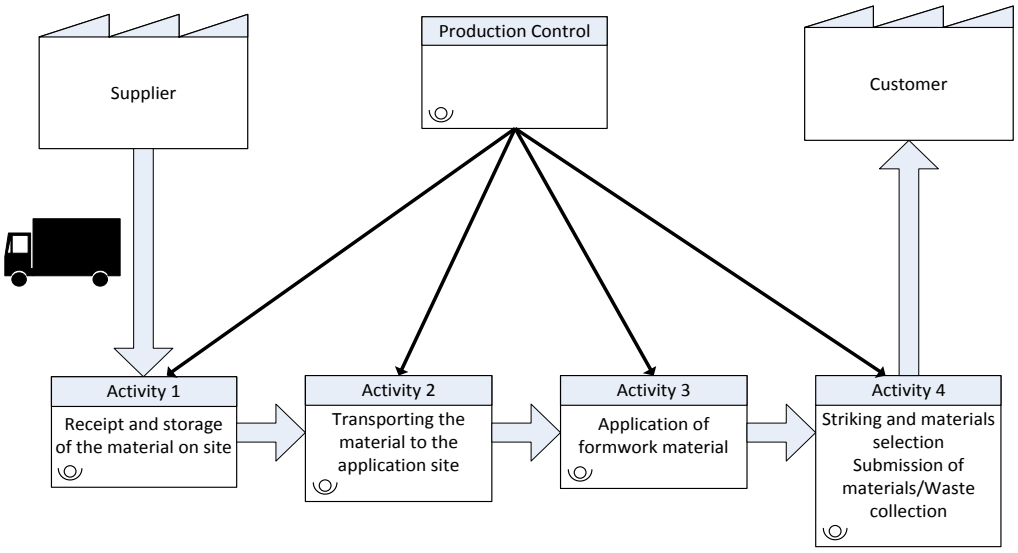

Figure 2: Future Value Stream Mapping

PULL PLANNING AND PPC

A fundamental difference between conventional construction and LC is its planning philosophy. Pull planning was previously described in this article and requires a constant assessment of the results obtained and their comparison with the respective weekly plan. This assessment is made based on the PPC. However, field observation in this case study exposed specific limitations of PPC in rehabilitation works, which were focused in its formal inability to register structured feedback on the causes for non-compliance. Rehabilitation works have a high level of unpredictability, and lessons learned in different jobs can hardly be used in subsequent ones. Thus, it is vital to analyze the root causes for non-compliance in the specific job in progress and record the conclusions for subsequent utilization in planning. A common tool for root cause analysis is the 5 Why's technique. It was found to be very useful to reach conclusions that led to the improvement of subsequent PPC's. Based on the combination of PPC and the 5 Why's, the authors proposed the "Map of Irregularities" presented in Table 3. Its main objective is to keep a systematic record of the causes of failure in each activity, in order to prevent their recurrence, thus avoiding recurring errors.

Table 3: Proposed Map of Irregularities

Map of Irregularities

Work:			**Week:**	
Activity number	**Designation**	**Fault Detected**	**Consequence**	**Suggested solution**

The assessment of the results of this measure would have taken longer than the time available for the completion of this study. Thus, it was not possible to quantify its benefits.

Still, the implementation of this tool was considered positive during the validation interviews with top management, which welcomed the author's suggestion to create a database by work type, in order to compile the information taken from these maps.

However, those responsible for the activities showed reluctance to fill those maps. This may be due to the fact that they resisted admitting and exposing failure. This indicates that maintaining this measure and its success will greatly dependent on persistence of the project management.

CONCLUSIONS

The objectives initially set for this study were achieved, both regarding the analysis of adequacy of LC principles and tools to rehabilitation works, and the selection and evaluation of benefits of Lean solutions in a case study.

It was concluded that pull planning can be applied to rehabilitation works, despite the high level of unpredictability. The use of a principle of PPC by the company studied indicates openness to adopt the use of Last Planner System in the near future.

It was further concluded that the implementation of the solutions chosen could not be done in a hasty way, requiring time, employee training and supervision by their managers, thus preventing sliding back to old habits. However, it was also concluded that experienced site management staff interested in optimization tends to acknowledge Lean solutions as "making sense". It was observed that some principles and tools of LC were being applied intuitively, which indicated openness to implement LC in this kind of works. The successful implementation of LC solutions to rehabilitation works requires knowledge of Lean by all stakeholders in the process, and a spirit of change and commitment.

FUTURE FIELDS OF RESEARCH

In order to expand this study, it would be interesting to repeat it in other rehabilitation works in buildings, in order to assess its generalization potential and define a pattern for implementation prerequisites and expected results.

It would also be interesting to conduct a case study on the optimization of the supply chain of this kind of works, making it more efficient, and subsequently evaluate the impact of its increased efficiency in the construction works.

There is a strong need in Portugal for survey studies of built heritage and its characterization. It would be of utmost importance to carry out these studies, as well as to create an "identity card" of the building, where all the interventions it suffered throughout its lifespan would be recorded. This would significantly reduce the unknowns associated to these works, thus increasing the effectiveness of the pull planning and LC solutions.

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