Lean Construction Impact on the Environmental Footprint of a Construction Project in Colombia: A case study

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ABSTRACT

The construction industry has positioned itself as one of the main drivers for economic growth and infrastructure development in the world. Nevertheless, this industry remains as one of the most polluting, non-environmentally sustainable, and less committed to the implementation of long-term solutions for sustainable development. Lean Construction, as a project management philosophy, has had a positive impact on resource efficiency and productivity of construction projects. However, there are still no several studies that have quantified the environmental impact of this philosophy.

The purpose of this research is to quantify the impact of Lean Construction on the environmental footprint of a project. The methodology of the study consists of a comparative case study, between two projects, one using lean construction principles and the order following a very traditional approach. Both projects were assessed from the environmental perspective through a life cycle analysis using Open LCA. The main results show that there is a quantifiable relationship between the implementation of Lean Construction and the reduction in the environmental footprint of the project in a range of decrease between 18-24%.

KEYWORDS
Lean Construction, Environmental Footprint, Climate change, Construction Project.

INTRODUCTION

This research aims to assess the impact of the implementation of Lean Construction on the environmental footprint of a project. The construction has historically had low efficiency; moreover, it has been one of the industries with lowest performance in terms of resources use, productivity, and pollution management (Rosembaum et al., 2012).

This paper begins with an in-depth study of the existing Lean Construction literature and the environmental footprint of a project, as well as the interaction of these two concepts. Next, the methodology to measure the environmental footprint that was carried out for the case study is explained. This methodology consists of a comparative case study of two very similar projects, one using lean construction and other using a more traditional approach. The performance of both projects is compared in terms of executed budget and schedule, assessing waste and delays. Having this, these delays and cost overruns will be quantified in each corresponding material category, to make a Life Cycle Analysis (LCA) in the two projects, in order to conclude whether Lean Construction effectively had an impact on the environmental footprint of the project. Finally, the case study is presented, analyzing the main results in order to reach conclusions and recommendations.

APPROACH TO LEAN-GREEN

Brundtland (1989) defines sustainable development as meeting the needs and aspirations of the present generation without compromising the ability of future generations to meet their needs. Nevertheless, such future stability is compromised by climate change. The menace of global heating and climate change may be the most critical issue for future development (Brundtland, 1989). This process is caused by the emissions of greenhouse gases due to human activity (Eggleston et al., 2006). These gases such as water vapor, carbon dioxide, methane, and nitrous oxide can absorb infrared radiation, trapping heat in the atmosphere causing global warming (Eggleston et al., 2006).

The construction industry, including the built environment, has been one of the industries with the most substantial contributions to greenhouse gases emission. The materials and manufacturing industry has a significant contribution, especially under the assumption that usually, fossil fuels are used as an energy source for most production processes (Kibert, 1994). The global pollution attributable to the build environment include: deterioration of air quality (23%); emission of greenhouse gases (50%); pollution of drinking water (40%); depletion of ozone (50%); and causing landfill waste (50%) (Brown & Bardi, 2001; Sertyesilisik, 2014).

According to Kyoto's protocol, the principal greenhouses gases attributable to the construction industry are $C0_2$, CH_4, N_2O, HFCs, PCFs, and SF_6. Consequently, an indicator must be determined to measure the retrogression in environmental performance. A 'footprint' can be defined as "a quantitative measurement describing the appropriation of natural resources by humans as well as how human activities can impose different types of burdens and impacts on global sustainability" (Sertyesilisik

et al., 2012). For instance, in a study carried out by Yu et al. in (2017), it was held that the construction industry could be responsible for generating 18,1% of Australia's total Carbon Footprint. These examples support that it is of great importance to reduce the environmental impact generated by construction projects. Therefore, it is essential to recognize which part of the value chain in Construction is generating a significant impact on environmental performance.

In this way, the environmental footprint appears as a holistic and suitable metric to identify the sources and quantities to measure the environmental impact (Ng et al., 2012). Construction consumes energy and other resources, generate substantial noise and other emissions, and produce large quantities of waste (Kibert, 1994). The construction projects must be considered as a network of interdependencies, with a potential contribution to the planetary balance and sustainable development (Augenbroe and Pearce, 1998; Huovila and Koskela, 1998; Salvatierra-Garrido et al., 2010; Novak, 2012). Historically, these operations in construction are recognized for low efficiency, massive waste, and few technological innovations. According to Kibert (1994), the construction must change its historical methods of operating that makes environmental a crucial point in its strategy.

According to Womack & Jones (2003), Lean is a systematic methodology that emerged from the Toyota production system (TPS). The main objective is to reduce everything that is considered waste in order to optimize the value of any operation. Based on this methodology, emerged Lean Construction. This methodology consists in the application of the Lean ideology to the construction industry (Koskela, 1992, 2000). It seeks to reduce waste, such as cost overruns, delays, and excess material in the construction process (Womack & Jones, 2003). Lean Construction brings many benefits to a project; it also may have an impact on the environmental aspect, although, it is not well documented. According to Valente et al. (2013), it is possible to identify interrelationships between LPS and green practices, principally in the small team in reducing wastes and sedimentation control site.

A new approach to this methodology is called Lean-Green, which consists of studying the synergy that exists between Lean Construction and Green Construction, or "Green Building." This last concept consists in having an ecologically responsible and environmentally sustainable construction. Rosenbaum (2012) argue that there is evidence of the potential benefits of using a "Green-lean" integrated approach to manage construction projects. Similarly, Ng (2015) argued that Lean and Green go hand in hand because being Lean means reducing waste; therefore, it is likely to improve resource efficiency and reduce environmental impact. This Lean-Green concept is relevant to the development of this study. It demonstrates that there is a direct relationship between Lean management and a positive impact on environmental performance (EPA, U., 2003; Koranda et al., 2012; Novak, 2012; Rosenbaum et al., 2012; Ogunbiyi O. & Goulding, 2013; Valente et al., 2013; Ng et al., 2015; Piercy & Rich, 2015; Fercoq et al., 2016; Martínez León & Calvo Amodio, 2016). Sertyesilisik (2014) concluded that the management of construction projects based on Lean principles could emphasize the reduction of the environmental footprint of the construction industry due to the effectiveness and efficiency. Principally in the reduction in waste, reduction in water usage, reduction in cost, and environmental

quality. (Koranda et al., 2012; Ogunbiyi O. & Goulding, 2013; Valente et al., 2013; Fercoq et al., 2016; Martínez León & Calvo Amodio, 2016)

METHODOLOGY FOR MEASURING THE ENVIRONMENTAL FOOTPRINT OF A CONSTRUCTION PROJECT AND THE IMPACT OF LEAN CONSTRUCTION

This study proposes a methodology for measuring the environmental footprint of a project and the impact of Lean Construction. A case study was chosen as the principal methodology approach, where the variables were quantitatively evaluated according to estimate the impact on the environmental footprint of two construction projects. Two projects with essential similarities in terms of location, dimensions, financial structure, and costs, were selected. One of the implemented most of the lean construction principles, while the other did not.

To determine if Lean Construction can contribute to minimizing the environmental footprint of a project, a Life Cycle Analysis (LCA) of the two projects was performed. The first step was to calculate the list of quantities of both projects, including waste for both projects. Moreover, a life cycle analysis was conducted on the principal materials such as concrete (including different strengths), steel and glazing, as those are the supplies in most considerable quantity in both projects and that have the most significant impact on the budget. The variable considered for the computational model was the material source, distances from the different distribution points of the supply chain. The LCA evaluates the impacts since the extraction of the materials, before the manufacturing processes until the end of construction. Considering this, there are many contributors to the environmental impact.

The software Open LCA was used to model flows, processes, and products systems for each project analyzed. This program facilitates the conversion of some variables obtained on-site, such as the number of materials, the transportation distance, and the waste into quantifiable variables that indicate environmental footprint. The previously defined quantities of materials are added to the processes of each project. The method used to perform the LCA was TRACI (Tool for the reduction and evaluation of chemicals and another environmental impact) from the United States Environmental Protection Agency (EPA). The TRACI method includes impact categories related to environmental impact and human health. TRACI environmental impact categories are acidification, ecotoxicity, eutrophication, global warming, ozone depletion, photochemical oxidation, the human health categories are carcinogenic, non-carcinogenic, and average respiratory effects (Bare, 2011).

With this analysis, it is possible to establish a numerical and quantifiable difference in the environmental footprint generated by the project that implements Lean Construction and a project in which the methodology is not implemented.

CONTEXT AND CASE OF STUDY

Colombia contributes to 0.46% of greenhouse gas emissions worldwide. Thus, the country does not have a significant contribution to greenhouse gases emission. However, its example in mitigating global warming may be an example for other countries in the region. Colombia is committed to reducing its greenhouse gas

emissions by 20% compared to the projected emissions by 2030 and signed the Paris agreement (García Arbeláez et al., 2016).

According to the National Administrative Department of Statistics of Colombia (DANE) in the annual report of (2019), the construction sector in Colombia contributed 7% to GDP in 2018. Besides, the construction industry is responsible for 5% of the country's emissions (García Arbeláez et al., 2016). Construction is a crucial sector in the Colombian economy. Even in other countries, participation is much higher; the improvements in management can make a significant difference in terms of sustainability.

The projects that are part of this study are from the same construction company. This company is medium-sized, dedicated to the structuring, development, and commercialization of real estate projects. As part of their strategic plan and research and development efforts, the company decided to build one project using the traditional methods they have always used, and other project implementing most of the lean construction principles. The first project, called Project A, was delivered using conventional project management approaches, where the teams were not integrated from the beginning and had a naive implementation of Lean construction. The second project, called Project B, was delivered with a more mature implementation of Lean Construction, in which the actors were integrated from the beginning, and there was feedback on the lessons learned from previous projects. There was also an interaction with contractors through the Last Planner System (LPS) and Concurrent Engineering (CE). The main principles and tools used in Project B are listed below:

- Last Planner System (LPS)
- Concurrent Engineering (CE)
- Value Stream Mapping (VSM)
- Just in time (JIT)
- Standard work
- Takt time
- Kaizen
- 5S
- Kanban
- Five whys

Both projects are entirely comparable as both are very similar at the construction process level, both are residential, both construction area 5000 m^2, the machinery used, and the construction techniques were the same. On the other hand, the end-user of the project has a similar profile, and the location of the project in the city is very close to each other.

DISCUSSIONS OF RESULTS

After using the list of quantities of both projects to create the processes in Open LCA, the TRACI method was used to determine the impact inventory and analysis in the life cycle of the materials previously described. The quantified impacts per impact category are shown in Table 1.

Impact	Impact category	Project B	Project A	Units
Environmental	Acidification	3,28E+05	4,20E+05	moles of H+ - Eq
	Ecotoxicity	8,08E+05	1,06E+06	kg 2, 4-D - Eq
	Eutrophication	3,20E+02	3,91E+02	kg N
	Global warming	1,74E+06	2,27E+06	kg CO2 - Eq
	Ozone depletion	9,18E-02	1,12E-01	kg CFC-11 - Eq
	Photochemical oxidation	4,12E+03	5,19E+03	kg Nox - Eq
Human health	Carcinogenics	4,50E+03	5,98E+03	kg benzene - Eq
	Non-Carcinogenics	1,88E+07	2,28E+07	kg toulene - Eq
	Respiratory effects, average	2,04E+03	2,69E+03	kg PM2,5 - Eq

Table 1. LCA of Project A and Project B

As can be seen in Table 1, all the impacts of the different categories evaluated produced in the life cycle of the materials of the project B, are lower than the ones of the project A. In the Figure 1 shows, the percentage decrease of the environmental impacts in the project B, the one that applied Lean Construction methodologies during its construction, compared with Project A.

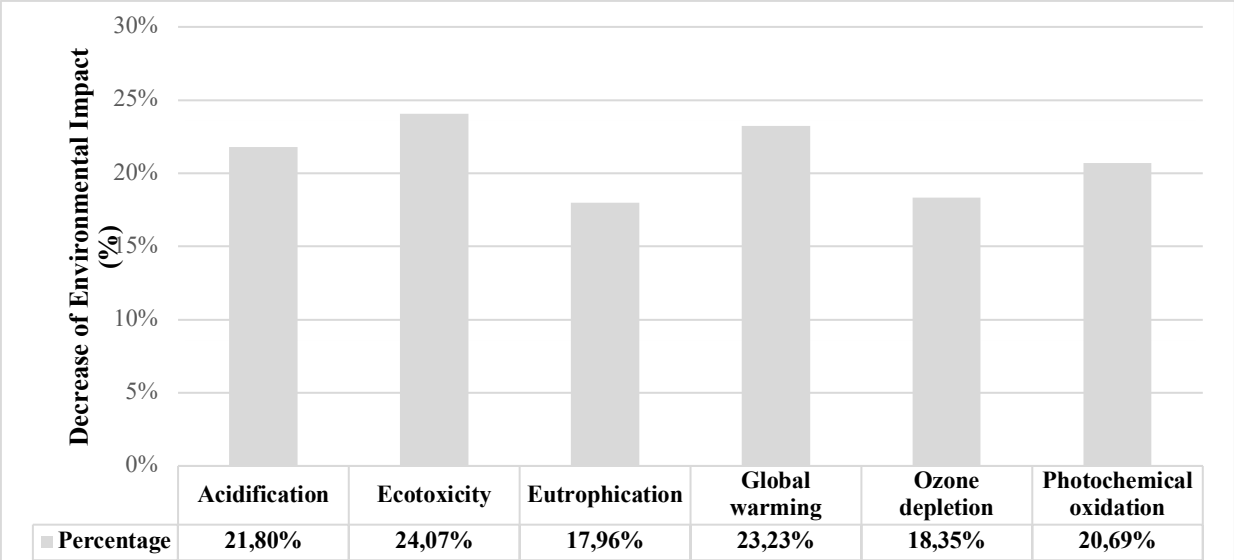

Figure 1. Decrease in Environmental impact with Lean Construction.

This study examines the effects of Lean Construction on the environmental footprint of a project and its impacts on human health. The findings present a correlation between the maturity of the Lean implementation and a decrease in the environmental footprint in Figure 1. A range of decrease in the different impact category of the project can be observed between 18- 24%.

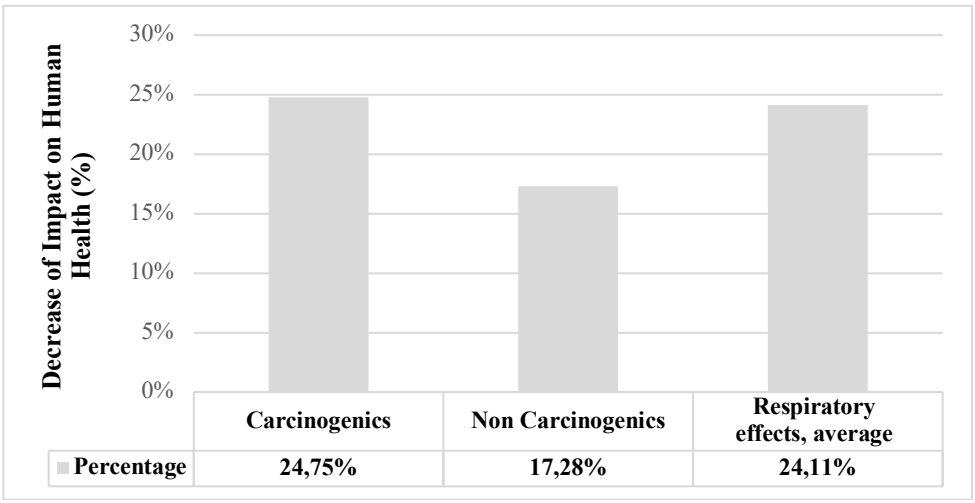

Figure 2. Decrease in impact on Human Health with Lean Construction.

The human health criterion is closely related to pollution, especially with particulate matter that is a quantity of small particles in ambient air that can cause adverse effects on human health, including respiratory diseases (Bare, 2011). A study guided by Oliver et al. (2001) concluded that in the heavy construction, the workers have an increased risk for asthma, and these workers have a higher mortality rate due to respiratory diseases. According to the results in Figure 2, there is a correlation between the implementation of Lean Construction and the reduction of health impacts within 17-25%.

Analyzing the contributors of Projects A and B, the main contributors to each impact category are quite similar. The main contributor for the eutrophication and ozone depletion is the petroleum production, for global warming and photochemical oxidation is clinker production, and for carcinogens and respiratory effects is the coking.

CONCLUSIONS

Global warming and other phenomenona caused by the anthropogenic influence can have a significant effect on human life and the possibilities of future generations. One of the industries that have contributed the most has been the construction industry. In order to guarantee sustainable development, many aspects of the construction value chain be improved. Lean Construction main objective is the improvement in the efficiency of the construction processes, which also has positive impacts on the environmental, social, economic, and cultural issues. The presented case study shows evidence of the direct relationship between Lean implementation and environmental impact.

The significant improvements are seen in the reduction of waste that is converted into better performance in the environmental footprint in a range of decrease 18-24% and decreasing in impact in human health result from the construction 17-25%. According to Colombia's announcements in the Paris agreement, the reduction in carbon footprint and ozone depletion would be essential impact categories to meet the established commitments. It is crucial to have a society much more aware of the severe problem that challenges the humanity, in addition, governments should encourage the private and public sector to carry out construction initiatives that improve efficiency, reduce waste and at the same time have better environmental performance.

For future research, the ideal is to investigate more in-depth about the impact categories and the diseases associated with construction; besides, an analysis of the importance of each category impact on the signing of the Paris agreement according to each country. In order to establish public policy recommendations that help generate changes in traditional construction methods that bring significant contributions to the worldwide sustainability. These improvements can be done considering the main contributors to the impacts and proposing alternatives. In addition, it is possible to quantify the impact that these emerging methodologies such Lean have on economic and cultural aspects.

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