

# COMPARING INVESTMENTS IN SUSTAINABILITY WITH COST REDUCTION FROM WASTE DUE TO LEAN CONSTRUCTION

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## ABSTRACT

The Architecture-Engineering-Construction industry shows some resistance in certifying (environmental labels) residential projects and applying lean construction practices due to uncertainty of its related costs and benefits. The most of the researches about green building certification costs are limited to commercial buildings. Few quantitative studies of cost reduction due to lean practices has been published so far. This paper presents a simplified comparative analysis between investments in sustainability and cost reduction due to reduction of materials' waste on a residential project.

The methodology consists of three steps: a documentation study to (1) quantify the extra costs with sustainable features in a LEED residential project and then (2) to determine the reduction of construction waste production by comparing the certified project with a similar building built prior the implementation of lean construction practices. (3) Finally, it was obtained green features and waste reduction costs impacts on the project's final budget.

This study resulted in two indicators, Green Cost and Lean Saving. The Green cost brought an increase of 1.32% on the initial budget due to green building certifications (LEED and INMETRO label) and the Lean Saving represented a 0.19% cost reduction on materials' waste. Thus, the Lean Saving represents 14% of Green Cost.

## KEYWORDS

Lean construction, sustainability, waste, green cost, lean saving.

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## INTRODUCTION

The Architecture-Engineering-Construction (AEC) industry is responsible for 40% of all waste generated by society (e.g. PNUD, 2012) and represents 8,8% of the Brazilian Gross Domestic Product (GDP) (e.g. ABRAMAT, 2013). To reduce the impacts of the AEC supply chain, the governments and the companies are investing in sustainable initiatives to apply on construction projects.

The effort to improve the process performance led the AEC industry to adapt the principles of Lean Production from the automotive sector to the construction sites. Koskela (1992) brought the concepts and practices of Lean Production to the AEC industry, idealizing the Lean Construction Philosophy.

One of the Lean Production, and thus of the Lean Construction, main goals is related to the total elimination of waste. Ohno (1997) states that the increase in efficiency is directly related to cost reduction: produce only what is necessary with the minimum manpower. An increase of efficiency is obtained when waste tends to zero (e.g. Ohno, 1997). Nevertheless, not many studies quantifying the cost reduction related to the Lean Construction practices have been published yet, mostly due the number of variables involved and the difficulties to identify and quantify it.

In addition to Lean Construction practices, the construction industry has seen the green buildings certifications as a way of reducing the environmental impacts of its activities. For Casado and Fujihara (2009), a green building allows its occupants a more responsible attitude in relation to energy and natural resources through a series of practices that look for efficiency during the building's life cycle.

However, according to the World Green Building Council (2013), there are some green building paradigms to be broken: a green building project and construction is not necessarily more expensive, the added value increases the building's market price, and reduces the operational costs.

## THEORETICAL BACKGROUND

The Leadership in Energy and Environmental Design (LEED) certification is one of the main green building certifications, known worldwide. Created in 1998 by the US Green Building Council (USGBC), LEED is in its fourth version and applies to many different building typologies.

LEED certification costs are discussed all over the world. Kats, Braman and James (2010) gathered cost data from 170 green buildings (schools, offices, hospitals, multifamily residential buildings, theatres, universities, etc.) that received LEED or an equivalent certification. They observed that the cost related to the green features vary between 0 and 18%, from which three quarters were concentrated between 0 and 4%. The average of the cost increase was 2%.

Jacomit, Granja and Silva (2009) gathered different studies about LEED certification costs and observed a variation from 0 to 21%. They analysed mostly offices, hospitals, schools and laboratories. Finally, Silva (2013) studied the costs of some sustainable features added to a residential building in Fortaleza, Brazil, resulting in 5.02% cost increase.

## RESEARCH METHODS

The methodology for developing this case study was developed by the authors and consisted of four steps:

- (1) A literature study to obtain the theoretical basis about lean construction and green building principles and practices.
- (2) The selection and characterization of the building's project and the company's historical experience with lean construction and sustainable practices.
- (3) Determine the Green Cost by gathering information on costs related to the green building certification processes (certification, design, and material and equipment costs). Determine also the Lean Saving by analysing the reduction of construction waste production after implementing lean practices on the construction site and the reduction on materials losses during the construction work.
- (4) Compare both Green Cost and Lean Saving.

## CASE STUDY DESCRIPTION

### OBJECTIVES

This research paper has the main objective to compare the financial investments to build a multifamily high-rise residential green building, to the cost reduction with waste due the lean constructions practices.

### THE CONSTRUCTION COMPANY

Founded in 1975 at Fortaleza, Brazil, the construction company of this case study focuses specifically to Classes A and B. It has more than 700.000m<sup>2</sup> of constructed area, distributed in various residential projects.

Since 2004, the company has been using many lean tools and practices: *kanbans*, *andon*, *poka-yokes*, supermarket concepts in the warehouses, transparency, production in small batches, new solutions formatted in the A3 tool, the standardized work tool and many others.

The company's interest for green buildings and environmental certifications started in 2009 to pursue a LEED certification for one of its residential projects. In 2014, the project was LEED Certified.

### THE PROJECT

The LEED Certified project analysed in this study is located in a noble neighbourhood in Fortaleza, Brazil. This building has been selected as a case study for being the first residential project LEED Certified in Brazil and due the company's interests in knowing the real costs during its certification process. Its project consists of a single tower with 23 floors and 3 apartments per floor. Table 1 brings the general information about this residential building.

*Table 1. General project information*

<b>Month / year completion</b>	November/2013
<b>Description</b>	2 parking garages underground, 1 ground floor, 21 standard floors and 1 penthouse floor (duplex)
<b>Units</b>	66 units (3 apartments per floor, 1 with 167,12m <sup>2</sup> and 2 with 151,14m <sup>2</sup> )
<b>Gross floor area of the building</b>	18.964,32m <sup>2</sup>
<b>Sustainability matrix grade (Meneses, 2011)</b>	9,70

The building is a LEED Certified project in the category Core & Shell. The certification process began in 2010, and was completed a few months after the completion of the project in 2014. To meet the prerequisites and a minimum of 40 points required to obtain the certification, some sustainable attributes were incorporated into the building's project, such as:

- installation of bike racks in the parking garages;
- rainwater reuse system installation, with VF1 filters;
- roof covered with white high-reflective painting;
- renewable energy use: installation of wind turbine;
- placement of energy efficient lamps and equipment;
- installation of aerator on taps and flow regulator in shower sets, etc.

The building has also the INMETRO Label Level A of energy efficiency for Common Use Areas, which influenced directly the settings of sauna equipment, lamps and lighting fixtures, pumps, elevators and other electrical equipment and appliances. Likewise LEED, to obtain this label it was necessary to meet the prerequisites: the three-phase induction electric motors installed have high performance; and in garages, it was provided a system of mechanical ventilation with automated carbon monoxide (CO) concentration detection. It is important to highlight that the exhaust system for basements is one of the requirements of the commissioning process demanded by LEED.

## **DEVELOPED ACTIVITIES**

This case study occurred into four major stages:

- **Definition of Green Cost:** the Green Cost is the sum of investments made by the construction company directly related to sustainable attributes incorporated into design and administrative costs due to environmental certification LEED for Core & Shell and INMETRO Label. The cost is treated exclusively as percentage.
- **Identify the Green Costs:**
- certification cost: registering and auditing of the project, documents translations and hired consultants;

- design cost: extra costs due design changing to meet the requirements of the certifications;
- costs of materials, equipment and services: investment in equipment, simulations, testing and materials directly related to both certifications requirements. It takes into account the costs of sustainable attributes added to the project exclusively related to the certifications requirements, the green features provided in previous projects were excluded because they are not additional costs. The administration team costs was discarded in this study.
- **Definition of Lean Savings:** lean practices such as long, medium and short term planning, kanban, Andon, poka-yokes, supermarket concepts at the warehouses, transparency, production in small batches, new solutions formatted in A3 tool, the standard work tools and many others are applied in this company for over 10 years. This became a great difficulty in determining the impact of lean practices on the final construction cost. The Figure 1 shows the main stages of Lean Savings defined by the authors. After looking for different indicators, it was decided to compare two similar projects to determine de cost reduction with waste. The LEED certified project was compared to the last project built before the implementation of lean construction practices.

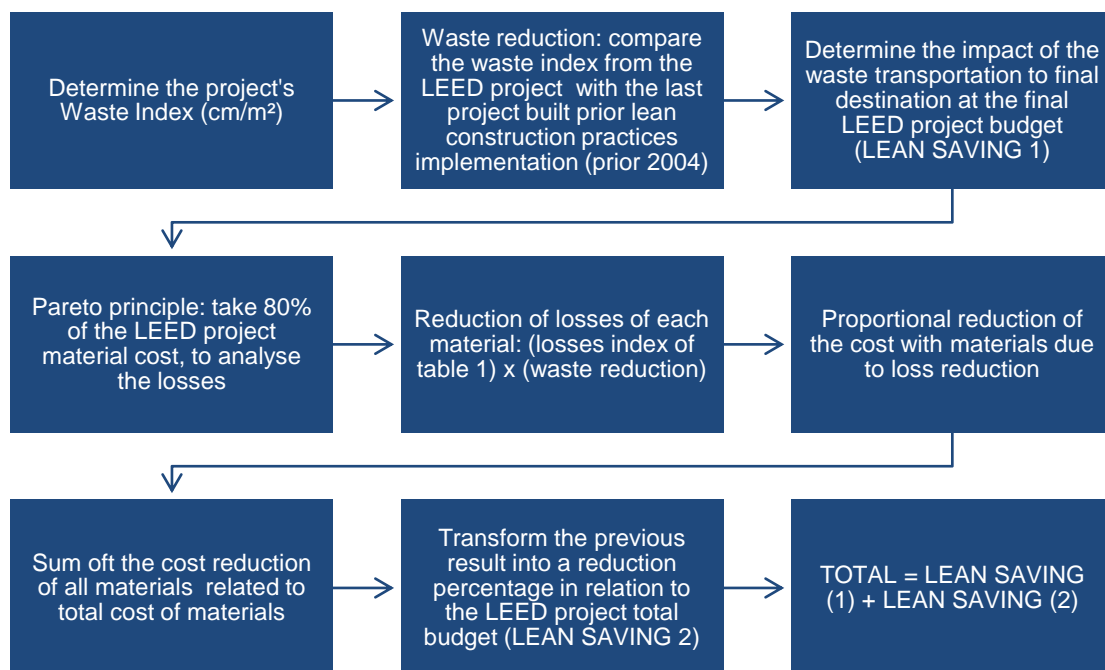


Figure 1. Flux gram of the actions to determine the Lean Saving.

The Waste Index consists of an imaginary layer of construction waste, its height is expressed in centimetres and it is determined by the relation between the total construction waste volume (expressed in  $m^3$ ) and the building's gross floor area (expressed in  $m^2$ ). The company follows monthly the Waste Index of each construction site since 2004.

**Indicators Analysis:** Once determined the Green Cost and Lean Saving parameters, it was performed a comparative analysis between the percentages obtained by checking if there was compensation for investments in sustainable attributes necessary for obtaining environmental certifications.

## RESULTS

### GREEN COST

Table 2 lists costs added to the project's budget due to sustainable attributes incorporated to meet the requirements for obtaining the LEED certification and meet label requirements of the INMETRO Label for the common areas.

*Table 2. Project's Green Costs (%)*

<b>Extra costs</b>	<b>%Green cost</b>	<b>%Final budget</b>
LEED pre-certification and certification processes	11.58	0.15
INMETRO Label certification process	4.41	0.06
<i>Total – Certification Costs</i>	<i>15.99</i>	<i>0.21</i>
Extra design cost – LEED	2.04	0.03
<i>Total – Design Costs</i>	<i>2.04</i>	<i>0.03</i>
LEED Pre-certification and certification – Exclusively	44.78	0.59
LEED + INMETRO Label – Common costs	26.07	0.34
INMETRO Label – Exclusively	11.49	0.15
<i>Total – Materials, Equipment and Services Costs</i>	<i>82.34</i>	<i>1.08</i>
<b>Total – Certification + Design + Materials, Equipment and Services Costs</b>		<b>1.32</b>

The investments were divided in certification costs, design costs, and costs of materials, equipment and services, for each certification and were analysed as percentage of Green Cost. As mentioned previously, the costs covered in this study do not include sustainable practices implemented in prior projects, as well as costs with employees responsible for certification process.

The results presented in Table 2 show that certification costs accounted for 15.99% of the total invested in sustainability, equivalent to 0.21% of the total building budget, with 11.58% related to LEED certification costs and 4.41% to labelling costs.

Since the decision to get these certifications was taken after the design phase, it was expected that several design changes would be necessary, mostly to meet the US standards referenced by LEED. However, the expectation was not confirmed. It was only necessary to include an exhaustion system on parking garages and adjust the electrical system design to ensure the energy efficiency required by both certifications. These design costs accounted for only 2.04% of Green Cost, or 0.03% of the total cost, and were attributed to project costs of LEED.

Costs related to materials, equipment and purchased services accounted for the largest share of the Green Cost, 81.97% (or 1.08% of the final budget).

Finally, it was analysed the impact of the Green Cost in the initial budget, dated from July 2011. The main costs of material, equipment and services were billed in October 2013; the initial budget was corrected by the Brazilian National Construction Index (INCC).

The investments exclusively related to LEED certification process correspond to an increase of 1.11% on the final cost, while the investments in the INMETRO labelling process correspond to an increase of 0.56%. However, as some costs are common to both certification processes, the combined investment resulted in an addition of 1.32% to the final construction cost (direct and indirect costs).

## LEAN SAVING

To determine the Lean Saving, we chose to analyse the production of waste during construction phase in relation to the last project built prior the implementation of lean construction practices on the company's construction sites.

At first, it was gathered the historical data of waste production (in m<sup>3</sup>) in the construction sites, from 2004 until nowadays (Figure 2). This project has generated 2,072.11m<sup>3</sup> of construction waste. Considering the gross floor area is 18,964.32m<sup>2</sup>, its waste index is 10,93cm / m<sup>2</sup>.

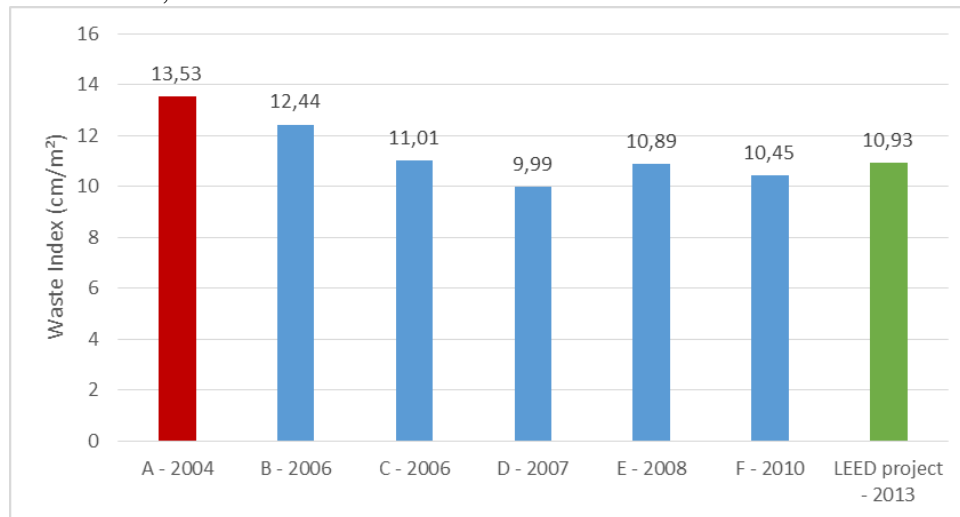


Figure 2. Waste index up to date

Comparing the LEED project with the A – 2004 project, we observe a reduction from 13.53cm/m<sup>2</sup> to 10,93cm / m<sup>2</sup>, which represents a reduction of 19.24% in construction waste production. It is important to note that the A – 2004 construction site did not have any lean practices and the LEED project construction site comprises almost ten years of learning and continuous improvement in the construction process.

The most recent Waste Index data shows less variation, indicating a trend: the indicator remains between 10,50cm/m<sup>2</sup> and 11,00cm/m<sup>2</sup>, which may be explained as both consolidation of lean practices and a barrier in relation to construction practices.

The cost of construction waste transport and disposal is about 0.33% of total budget, thus due to the reduction of 19.24% in waste production; there was a saving of 0.06%. In the past 10 years, besides the waste reduction, the company observed a smaller material loss index, resulting in 0.13% saving in cost with materials. Thus, the total Lean Saving of 0.19%, which represents 14.45% of the Green Cost obtained previously.

## **CONCLUSION**

Despite the waste cost reduction and smaller purchase of materials were unrepresentative in relation to the total cost of the project (only 0.19% of the total construction budget), the Lean Saving compensated around 14% of investment in green building certifications.

Moreover, this saving took into account only the reduction of materials losses and a more comprehensive analysis tends to obtain higher percentages. We emphasized that this study did not take into account the costs with employees responsible for managing internal lean practices in the company, as well as cost implementation of lean construction.

It is important to note that the literature on lean construction costs reduction are not numerous, mostly refers to a qualitative analysis of lean practices benefits on a project's final budget. Therefore, the lack of data for comparison gives the results achieved a first impression about the financial impact of lean at the final budget of a residential building.

However, the fact that this project has generated 20% less construction waste (in volume) when compared to a construction site without any concern in process improvement, has a huge value on environmental perspective.

Furthermore, the additional cost to the initial budget due to green building certifications observed on this case study (1.32%), was almost 20% smaller than the average reported by World GBC's survey (Kats, Braman and James, 2010).

## **CASE STUDY LIMITATIONS AND DIFFICULTIES**

We emphasize that this case study has very specific conditions, restricted to the evaluation of a residential building whose builder presents multiple green initiatives and applies lean practices in its construction sites for over a decade. The construction company overcame the initial stage of learning, thus the Lean Philosophy concepts were matured and perfected over the years and were incorporated into its processes.

Note also that the investments made in the implementation of lean practices (training, training, acquisition of equipment and tools) were not accounted, as well as any maintenance costs of these practices, whether in relation to materials and equipment or in respect of employees responsible for managing the lean construction in the company.

It is important to highlight that this paper was also restricted to analysis of the waste reduction related to materials and it was based on theoretical rates of material loss. This limitation is justified because an extensive search in the available literature on the lean construction showed that there are not many records of its impact on the final cost of a construction work. From the difficulties of determining the Lean Saving, we concluded that a detailed study on the costs impacts of lean philosophy involves complex variables whose quantification were impossible in this study.

## **FURTHER RESEARCH**

- Repeat Green Cost analysis provided to other residential or non-residential projects and to other companies with different level of certification and / or other environmental certifications such as the AQUA Process;



- Determine the impact of water and energy savings in operating cost of green buildings and calculate the payback time of the investments required for its construction;
- Conduct a survey of actual rates of material losses on construction sites;
- Determine the costs of implementing the Lean Philosophy in a construction sites due to investment in education and training of employees, in equipment, materials and services;
- Verify the savings provided by lean construction related to labour by reducing effective in the construction site, reducing the number of hours worked and / or productivity gains of the teams.

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## REFERENCES

- Associação Brasileira Da Indústria De Material De Construção (ABRAMAT), 2013. *Perfil da cadeia produtiva da construção e da indústria de materiais e equipamentos*. 2013. Available at: <<http://www.abramat.org.br/site/datafiles/uploads/Perfil%20Cadeia%20Produtiva%202013%20vfinal.pdf>> [Accessed 24.11.2014]
- Casado, M; Fujihara, M.C., 2009. *Guia para sua obra mais verde. Guia prático sobre construções sustentáveis nas cidades*. São Paulo: Green Building Council Brasil.
- Jacomit, A.M.; Granja, A.D.; Silva, V.G., 2009. *Construções sustentáveis realmente precisam custar mais do que construções convencionais?* In Simpósio brasileiro de gestão e economia da construção: João Pessoa.
- Kats, G; Braman, J.; James, M. 2010. *Tornando nosso ambiente construído mais sustentável*. Washington: Island Press, 2010. Translated from English by Secovi-SP: São Paulo.
- Koskela, L. 1992. *Application of the New Production Philosophy to Construction*. Stanford, CA: Stanford University, Center for Integrated Facility Engineering (CIFE).
- Meneses, L.O. 2011. *Indicadores de sustentabilidade para edifícios residenciais verticais em Fortaleza/CE*. Paulista University: Fortaleza.
- Ohno, T. 1997. *O Sistema Toyota de Produção: Além da produção em larga escala*. Translated from English by C. Schumacher. Porto Alegre: Bookman. 149p.
- Programa Das Nações Unidas Para O Desenvolvimento (PNUD). 2012. *Buildings: investing in energy and resource efficiency*. In: Towards a green economy: pathways to sustainable development and poverty eradication. Available at: <[http://www.unep.org/greeneconomy/Portals/88/documents/ger/9.0\\_Buildings.pdf](http://www.unep.org/greeneconomy/Portals/88/documents/ger/9.0_Buildings.pdf)> [Accessed 01.12.2013]
- Silva, S.R., 2013. *Estudo do impacto financeiro da implantação de atributos da construção verde no orçamento de uma obra residencial vertical*. Federal University of Ceará: Fortaleza.

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World Green Building Council. 2013. *The business case for green building – A review of the costs and benefits for developers, investors and occupants*. 2013. Available at:  
<[http://www.worldgbc.org/files/1513/6608/0674/Business\\_Case\\_For\\_Green\\_Building\\_Report\\_WEB\\_2013-04-11.pdf](http://www.worldgbc.org/files/1513/6608/0674/Business_Case_For_Green_Building_Report_WEB_2013-04-11.pdf)> [Accessed 08.11.2013]