LEAN AND GREEN: A RELATIONSHIP MATRIX

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ABSTRACT

Lean Construction is associated with the implementation and adaption of concepts and principles of the Toyota Production System in civil engineering management, its main objective is to reduce waste through process improvement, to optimize flows and increase product quality. The LEED system was created to ensure sustainability, seeking to reduce the environmental impact of construction through a rational use of existing resources. Based on these two concepts, this study aims to build a matrix of interaction between the sustainable guidelines on civil construction, considering the criteria for certification of environmental performance of buildings, and the principles of Lean Construction, to understand the complementarity between Lean and Green. This is a theoretical research, which comprises the following steps: a literature review about the principles of Lean Construction and the process of environmental certification of buildings, with emphasis on the LEED certification; and finally, the construction of an interaction matrix between Lean and Green, considering their positive direct interactions. The results of the analysis show a number of interactions between the principles of Lean and Green Construction. Among these, it stands out the search for the general elimination of waste and the addition of value to the customers, confirming the importance of this research approach.

KEYWORDS

Theory, Lean Construction, LEED, Interaction matrix.

INTRODUCTION

The Lean Construction (LC) and LEED NC ® certification are objects of study in this paper. While the prior has the waste reduction as its primary goal, the later aims at reducing the environmental impact of buildings through the rational use of resources.

The discussions relative to the concept of LC began in 1992, when Lauri Koskela published a work called "Application of the new production philosophy in the construction industry", focused on the conduction of production flows that sets the concept of value as a result of the quest for quality. According to Koskela, the objectives of LC philosophy might be achieved by pursuing the eleven principles described by his work, and presented later at this paper.

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Through his technical report, Koskela (1992) invites construction professionals to shift their management paradigms and to adept the techniques and tools successfully developed by the Toyota Production System. During the design and production of a building, the LC covers the following activities: conversion, inspection, waiting and moving. All these activities require time and resources, but not all of them add value to the product. Thus, it raises the need to minimize or eliminate some of these activities.

Regarding to sustainable construction, the Conseil International du Batiment (CIB) defines it as the conception and development of a healthy construction process, based on efficient resource and ecological design. The CIB has postulated seven principles for sustainable construction: reduce resource consumption, reuse resources, use recyclable resources, protect nature, eliminate rubbish, apply lifecycle costing and focus on quality. During the entire construction cycle, these principles are applied to all the resources: land, materials, water, energy and ecosystem (Kibert 2007).

Due to the lack of global consensus for comparison of sustainable attributes, the definition of sustainable building is still subjective. Different programs have been created in several countries, such as: the *Building Research Establishment Environmental Assessment Method* (BREEAM), released in the UK in 1990; the *Building Environmental Performance Assessment Criteria* (BEPAC), developed in Canada; the American certification Leadership in Energy and Environmental Design (LEED NC®); the French certification *Haute Qualité Environnementale* (HQE). In Brazil, there is a program focused on low income housing called *Selo Casa Azul* promoted by the federal bank Caixa Econômica, and the *Programa Nacional de Conservação de Energia Elétrica* (PROCEL) which has developed an energy-efficiency label.

According to Kats (2003), sustainability can be considered a holistic concept, meaning that each methodology determines or prioritizes different green attributes in their criteria. While the American certification LEED NC® takes into consideration project definitions, construction process and the impact caused at this stage of the building lifecycle, the Brazilian energy-efficiency label only takes into account projects related to electricity rationalization. According to Kibert (2007), the American certification LEED NC® is currently the prevailing instrument of environmental assessment of buildings in the United States and perhaps in the entire world.

The building is an enterprise whose lifecycle can be divided into the following stages: idealization, conception, design, construction, use, maintenance and demolition. Despite the fact that greater energy consumption in construction is presented during the stages of use and maintenance, interventions performed at the stages of idealization, conception and design aiming to reduce these impacts may result in a building with a better performance at a lower cost (Motta and Aguilar 2009).

Considering that the sustainability guidelines approach all the stages of a building lifecycle and that the LEED NC® also approaches all these stages, its criteria were set as reference material to the study of green buildings.

Based on these concepts, this research aims to analyze the complementarity between the lean and green by building a matrix of interaction between the sustainability guidelines of the LEED NC® certification and the LC principles.

CONCEPTUAL RELATION BETWEEN LEAN PRINCIPLES AND SUSTAINABLE CONSTRUCTION

It is known that the Construction Industry is one of the most polluting and one of the largest waste producers throughout its lifecycle (Horvath 2004). The construction activities and the built environment produce enormous impact on human health, natural environment and the global economy. Due to these facts, there is great potential in advancing towards sustainable development (Nahmens and Ikuma 2011).

The implementation of LC reduces waste and improves construction flows, generating economical advantages. However, besides these economical advantages, it is essential to also improve the social and environmental aspects during the construction lifecycle, ensuring sustainability. Therefore, the following questions arise: how does the implementation of LC principles impact the construction and operation of sustainable buildings? What is the complementarity relation between the lean and green philosophies?

Some authors believe that through the LC it is possible to increase environmental benefits (Horman et al. 2004; Huovila and Koskela 1998; Lapinski et al. 2006, Luo et al. 2005, Riley et al. 2005), provided there is waste elimination, pollution prevention and value maximization for customers. The production and interaction between the two philosophies began to be implemented in construction projects (Mao and Zhang 2008; Gutierrez 2007; Kohler and Lützkendorf 2002), since the realization of progress and positive effects on the AEC industry.

However, other researchers report that there is no significative relation and some studies even argue that the implementation of LC can have a negative impact on environmental performance (Cusumano 1994; Rothenberg et al. 2001). The focus of the LC philosophy is to add value to its product based on the customer's needs, which is not always related to the reduction on environmental impacts.

Considering the interaction between the topics, through their affinities and disconnections, it is important to evaluate how LC and green act during the different stages of a building lifecycle. Azhar et al. (2011) claims that the LEED NC ® acts as a system of classification and measurement of the building sustainable performance, being highly influenced by the decisions made during the conception and design of buildings. In its turn, LC aims at the study of flows and conversion processes, considering the production control as a key activity. However, Bae and Kim (2007) point out that - when implemented during the design stage of projects - the lean practices may reduce costs and increase sustainability.

Sustainable development doesn´t only focus on environmental issues, but also includes two other perspectives: economic and social development. Thus, the lean philosophy can provide a concrete basis in these three areas. According to Bae and Kim (2007), the main impacts of the use of LC methods aiming sustainability are:

- Economic perspective: possibility of reducing operational costs in advance, saving of resources, reduction of operational costs and capability of increasing performance.
- Social perspective: safe workplace, people's health, community well-being, loyalty among stakeholders and improvement of the external image.

- Environmental perspective: eliminating the use of limited resources, preventing pollution by eliminating waste and preservation of resources.

Yates (2001) states that the positive impacts of the implementation of lean methods in the production of green buildings will be felt primarily at the economic perspective.

Based on the theoretical foundations described above, the following hypothesis was formulated: LC may contribute to more sustainable buildings, as they add value to the customer, intervening not only at the time of construction, but also at the stages of conception and design.

RESEARCH METHOD

This paper draws a theoretical proposal for understanding the interrelations between LC and green based on the literature and the authors' arguments. This is made from a matrix that connects lean principles and LEED NC® criteria, establishing theoretical relations in order to identify the constructive interactions between them.

In alignment with the goals of the research, during the development of the work, the following steps were followed: (1) Literature review involving the LC principles based on the work of Koskela (1992) and the study of the prerequisites and environmental sustainability criteria specified by the LEED NC® Certification for New Construction and Major Renovations; (2) Construction of an interaction matrix where the universe of sustainable criteria were crossed in line with the principles and philosophy of LC in columns - 57 prerequisites and criteria of the LEED NC® were reduced to 43 by grouping criteria with similar intentions, such as: "Heat Island Effect-Nonroof " and “Heat Island Effect-Roof”; (3) Matrix evaluation of direct positive relation between a certain principle and a certain criteria; (4) After completing the matrix, the impact of the interaction of each principle in relation to the criterion is analyzed, discussing the correlation found, and searching for the complementary relation between the lean and the LEED NC®.

LEAN PRINCIPLES

In this research, it was used the traditional list of eleven principles for the management of processes proposed by Koskela (1992). The application of these principles is the key to transforming the traditional concept of production, through evidence of the need to improve flow activities and increase value generation. The principles are explained as follows:

Reduce the share of non value-adding activities – Based on the information requested by the client, the activities can be as value-adding and non value-adding. All activities consume resources and time, but the conversion activities are responsible for adding value as opposed to moving, waiting and inspecting activities. Therefore, the three later should be minimized.

Increase output value through systematic consideration of customer requirement – It is necessary to evaluate and consider the requirements of customers in each phase.

Reduce variability – The variability increases the volume of non value-adding activities. Besides, the uniform product guarantees better quality. In order to reduce variability it is important to sort out the activities according to their sequence of development.

Reduce the cycle time - Time is considered the natural metric system for the flow process. Therefore, reducing cycle time eases management, reduces interruptions of the production process, and accelerates delivery to the customer.

Simplify by minimizing the number of steps, parts and linkages - This principle defines the simplification of the production process by reducing the number of product components, the number of steps in the flow of material and information, and eliminating non value-adding activities.

Increase output flexibility: Involves the production of a modularized product and the minimization of the lot sizes, to allow its easy customization at the end of process and the reduction of difficulties on changeovers.

Increase process transparency – This principle defends the process and layout organization, the use of visual controls and the implementation of informational and signaling systems. The goal is to ease the visualization of the process, since flaws in the process transparency increase the tendency to errors and reduce the motivation for improvement.

Focus control on the complete process - Supports the evaluation and control of the process as a whole, conducted by the responsible professional.

Build continuous improvement into the process – The goal is improving control by setting stretch targets, measuring and monitoring improvement. The responsibility for this principle's fulfillment must involve all employees.

Balance flow improvement with conversion improvement – The more complex the production process, the greater the impact on the flow. More controlled flows aid the improvement of conversions, ensuring less variability and greater efficiency.

Benchmark – This principle requires knowing the process, assessing the strengths and weaknesses of subprocesses; knowing the industry leaders or competitors, finding, understanding and comparing the best practices. The incorporation of these practices is responsible for the improvement and modification of subprocesses.

PRINCIPLES LEED NC®

The LEED certification system evaluates the environmental performance considering the full building lifecycle. It can be applied to commercial, institutional, residential buildings and others. The evaluation consists in the fulfillment of prerequisites and adoption of criteria to classify the building in the following levels: Silver, Gold or Platinum. In this research, the construction of the matrix involved the LEED NC®, which is responsible for new construction and major renovation projects (USGBC 2009). The seven categories of the certification system are as follows:

Sustainable Sites - involves the reduction of the environmental impact from the location of a building on a site; soil selection considering the urban density and connection to the community; rehabilitation of damaged sites; stimulus to occupy areas with good public transportation system; protection and restoration of habitat; maximization of green areas linked to the building; control and treatment of rainwater; control of heat islands through appropriate use of coverage and vegetation, and light pollution decrease (USGBC 2009).

Water Efficiency - suggests the rational use of potable water focusing on the reduction of consumption through the installation of smart devices and the reuse of

rainwater, wastewater and water from air conditioner condensate in the irrigation of gardens or toilet and urinal flushing (USGBC 2009).

Energy and Atmosphere- has the highest score among the seven criteria, which primarily seeks to improve the energy performance of buildings, encouraging the use of systems of self-supplying energy, renewable energy and gas management for reducing the damage of the ozone layer.

Materials and Resources- proposes to reduce the waste caused by construction that would be transported to landfills. The requirements and criteria established for this reduction not only rely on waste management and reuse of materials and products, but also encourage the reuse of part of existing building. It also stimulates the responsible management of forests, the use of certified wood and materials manufactured in the region, increasing demand for products extracted and manufactured in the region of the building (USGBC 2009).

Indoor Environmental Quality - involves the establishment of minimum indoor air quality, to promote comfort and well-being of users and the control of tobacco smoke in indoor environment. It also defends the adoption of indoor air quality management plan, reducing problems during the construction and preoccupancy phases; the use of low-emitting materials; control of lighting systems, thermal comfort, heating, ventilation and air-conditioning; and introduction of daylight and views into the building (USGBC 2009).

Innovation in Design - aims to encourage the initiatives of the team project that could go beyond the certification criteria, applying strategies or measures that demonstrate exceptional performance achievement. It also claims that at least one team member must be accredited by an LEED NC®, which is able to guide other team members and rationalize the process of application and certification (USGBC 2009).

Regional Priority - consider regional diversities of countries, to incentive the achievement of credits that address geographically-specific environmental priorities (USGBC 2009).

RESULTS

While preparing the matrix, it was observed that due to conceptual differences some LC principles do not dialogue with the prerequisites and the credit criteria for LEED NC®. This might be explained by the fact that the LEED NC® acts as a system of classification and measurement of sustainable performance of the building, being strongly influenced by decisions made during the conception and design of buildings, while the LC focuses especially in manufacturing processes, thereby, in the stage of construction.

In the analysis of interaction, the relation of each principle with the full universe of prerequisites and credit criteria of sustainability of the LEED NC® was described in a general manner, as shown in Table 01. The results of this evaluation were divided into three groups: principles that do not directly correlate with the criteria; principles that would conceptually relate to the criteria in an indirect way; and principles that have direct relations with some criteria.

Table 1: Matrix of relation between the 11 LC principles and the LEED NC ® criteria.

		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
	LEED X LEAN CONSTRUCTION	Reduce the non value-adding activities	Customer Value	Reduce variability	Reduce cycle times	Simplify by minimizing the number of steps	Increase output flexibility	Increase process transparency	Focus control on the complete process	Continuous improvement	Improved flows and conversions	Benchmarking
Sustainable Sites	Construction Activity Pollution Prevention											
	Site Selection											
	Development Density and Community Connectivity		✓									
	Brownfield Redevelopment											
	Alternative Transportation		✓									
	Site Development		✓									
	Stormwater Design		✓									
	Heat Island Effect		✓									
	Light Pollution Reduction		✓									
Water Efficiency	Water Use Reduction		✓							✓		
	Water Efficient Landscaping		✓							✓		
	Innovative Wastewater Technologies		✓							✓		
	Water Use Reduction		✓							✓		
Energy and Atmosphere	Fundamental Commissioning of Building Energy Systems		✓	✓						✓		
	Minimum Energy Performance		✓									
	Fundamental Refrigerant Management		✓	✓						✓		
	Optimize Energy Performance		✓							✓		
	On-site Renewable Energy		✓									
	Enhanced Commissioning		✓							✓		
	Enhanced Refrigerant Management		✓							✓		
	Measurement and Verification		✓							✓		
	Green Power		✓									
Materials and Resources	Storage and Collection of Recyclables			✓								
	Building Reuse		✓			✓						
	Construction Waste Management			✓						✓		
	Materials Reuse					✓						
	Recycled Content											
	Regional Materials				✓							
	Rapidly Renewable Materials											
	Certified Wood		✓							✓		
Indoor Environmental Quality	Minimum Indoor Air Quality Performance		✓									
	Environmental Tobacco Smoke (ETS) Control		✓									
	Outdoor Air Delivery Monitoring		✓							✓		
	Increased Ventilation		✓							✓		
	Construction Indoor Air Quality Management Plan			✓						✓		
	Low-Emitting Materials									✓		
	Indoor Chemical and Pollutant Source Control		✓							✓		
	Controllability of Systems		✓							✓		
	Thermal Comfort		✓							✓		
	Daylight and Views		✓							✓		
Innovation in Design	Innovation in Design									✓		
	LEED Accredited Professional			✓								
Regional Priority	Regional Priority		✓									

The first group is formed by the LC principles in which no direct relation with the environmental certification criteria could be observed: reduce the share of non-value-adding activities (P1), reduce the cycle time (P4); increase output flexibility (P6), and balance flow improvement with conversion improvement (P10). Principles P1, P4 and P10 are directly related to studies of the flows and conversions, seeking rationalization of the stages of activities (conversion, inspection, waiting and moving).

However, the improvements suggested by these principles could not be encompassed by the LEED NC®, due to its nature of building characterization. The design interventions proposed by the LEED NC® criteria, not only lack focus on the reduction of stages, but also may eventually increase the cycle time. As principle P6, no relations were found, as the LEED NC® is not a program that seeks flexibility, but the building certification by meeting certain requirements.

In the second group are the Lean principles that relate in a general manner to the LEED NC® purposes, but lack the focus on specific requirements and criteria. Considering the Lean principle of increasing process transparency (P7), it can be stated that the LEED NC® criteria are proposed in a clear and transparent way, as a checklist. Individually, however, none of the certification credit criterion is able to improve the clarity and transparency in the production process the same way carried out by the LC principles. Focus control on the complete process (P8) supports the evaluation and control of the process as a whole, clearly defining management roles and responsibilities of all the professionals involved. Regarding the sustainable guidelines, the correlation of this principle could only be observed in a general or an indirect way, due to the way in which the LEED NC® certification is proposed. However, it was considered one single criterion directly related to this principle, this criterion involves the presence of a professional accredited by LEED NC® (AP), who will be responsible for assisting the process of certification. The implementation of the LEED NC® consists in a benchmarking tool itself (P11) certifying that a certain building is green.

Finally, in the last group are the principles and analyzes of the direct interactions found in the matrix. The largest number of direct relations was found in the lean principle that recommends the increase in product value through the consideration of customer needs (P2). This happens because the LEED NC® criteria seek to directly improve both the quality of life of its users and the sustainable building performance that will directly influence the costs of post occupancy. LEED NC® requirements and criteria also allow correlations with the principle of continuous improvement into the process (P9). Among these criteria are the elements of the checklist that address control and monitoring tools of systems in buildings.

Variability reduction (P3) can be achieved by following some criteria required to accomplish LEED NC®. These are criteria that allow a higher standardization of design and construction processes. For example: commissioning of building energy systems, fundamental refrigerant management, construction waste management, storage and collection of recyclables, management plan for indoor air quality performance and the inclusion in the process of a professional accredited by the LEED NC®. As for the criteria of environmental certification, it was noticed the lack of incentive for rationalization and simplification of construction systems, which could contribute to simplify and minimize the number of stages (P5) and to reduce variability (P3). Thus, the only items in which direct relations were found are "building" and "materials reuse".

Taking into consideration the 43 LEED NC® criteria and requirements and the 11 LC principles used in the construction of the matrix, there is the possibility of 473 interactions. However, only 60 intersections between principles and criteria were actually found, corresponding to 12.68% of the relations. This is influenced by the

conceptual differences between the LEED NC® and Lean, although the two concepts value the reduction of waste and encourage improvements to the buildings.

CONCLUSIONS

This research developed a correlation matrix between the LC principles and the LEED NC® criteria that highlighted their interactions. Evaluating the intersections of the matrix, few interactions were found. Although both reflect benefits in constructions, by reducing waste and establishing competitive advantages, they have conceptual differences that impair more effective relations.

The LEED NC®, a certification tool with normative character, does not allow the flexibility valued by LC. It also does not help in the reduction in time and costs, because it doesn´t focus on the improvement of processes and it also suggests expensive sustainable interventions and the use of special facilities which may result in a greater resource investment. Another shortcoming of LEED NC® is the absence of criteria concerned with improving the working conditions and safety during the conception and construction. There is neither incentive to improve the layout of the construction site, nor the importance of signaling and communication is mentioned. LEED NC® also does not address the rationalization and standardization of procedures and constructive elements. Even in the ways of reducing waste, there are differences between the correlated concepts. LC focuses on reducing initial costs, but it shows no effective concern in reducing waste in favor of environmental performance.

The major difference between lean and green involves the method of application of the two approaches. While on its checklist, LEED NC® determines which "green" features to be linked to the enterprise during the conception, design, and construction, LC involves mainly flow and conversion processes, focusing on the productive process. However, it is noteworthy the project importance on constructability, which can directly influence production.

Considering the hypothesis of this work, it can be concluded that the LC can contribute to green building in a significantly way, because it interferes in the three spheres of sustainability: economic, environmental and social. Although the few direct relationship between LC and LEED®NC found in constructed matrix, the two philosophies can be used in a complementary manner. Their application in conjunction can add value to customer, optimize resources and bring improvements to building.

As for future work, this research suggests the validation of the interaction matrix in a case study involving construction enterprises that intend to apply the LEED NC® and LC, and also the debate with experts in the area to deepen the study of interactions between the two approaches, taking into account both the direct and indirect relations. Finally, it´s also suggested the construction of another matrix involving the relations between the LEED and Lean Design, having in mind that the certification should be considered since the conception stage.

ACKNOWLEDGMENTS

The authors wish to thank the Group for Research and Consultancy in Construction Management (GERCON), Federal University of Ceará (UFC), FUNCAP and CAPES for granting scholarships for our Master’s Degree.

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