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Design of industrial buildings: When lean meets sustainability

Theodora Mavridou *, Alexandros Tsigkas

Department of the Production and Management Engineering, Democritus University, Greece

Abstract

The construction of industrial plants involves the use of large material quantities to cover their structural requirements (large openings, increased equipment loads etc.) with both production as well as transportation and erection having a significant environmental effect. It is becoming increasingly important for the stakeholders involved to explore the relationship between industrial construction and sustainability. Much of the research revolves around the relationship between industry and sustainability, but few about the relationship between building construction and industrial sustainability. This article is an exploration between the relationship of sustainability with Lean thinking in the backdrop of sustainable and Lean construction. Although there has been a lot of research behind those topics in separation there is a lack of research that explores the relationship between Lean and sustainable construction and how by successfully utilising those in unison can bring about great environmental, economic and social gains and benefits.

Keywords: Industrial Building; Lean Construction; Sustainability

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* Corresponding author. *E-mail address:* dora.ch.mavridou@gmail.com

1. Introduction

The construction sector plays an important role in the progress of a society. Its influence on economic activity and employment and growth rates is huge as well as it affects on the natural environment and human health. The above make sustainable development an important factor to be taken under consideration in improving living conditions worldwide (Nahmens and Ikuma, 2009). In recent years, there have been developments in construction industry that render the whole process more environmentally friendly than ever. However, sustainable construction has maintained its focus on residential and office buildings, while the industrial buildings sector has been overlooked. Sustainability assessment and design tools specifically for industrial buildings are virtually non-existent, resulting in bibliographical and legislative shortcomings for these types of structures. While much research has been carried out on the pollution caused by the production process or industrial activity throughout the building's life cycle (air, noise, water, etc.), waste treatment or recycling, less attention has been paid to the building itself. The industrial sector is one of the largest energy consumers. In 2011, the industrial sector used 26% of total energy consumption (Eurostat, 2013), while in the US it used 31% (EIA, 2012). Although energy is used in production processes, manufactured products and the operation of buildings, only 7.5% of the total energy consumption of the industrial sector came from renewable energy sources in 2011 (EIA, 2012). Those are the reasons behind the pressing need of intensifying research efforts towards the construction and manufacturing industry that can offer multiple benefits in economic, social and environmental terms.

Research conducted in 15 different sectors in the US (ORNL, 2012) showed that about 15% of energy consumption is "wasted" on non-productive/manufacturing activities, while more than 80% is spent on lighting and air conditioning. Due to the large volumes usually found in industrial areas, saving energy for lighting and air conditioning can be a significant factor, since even a minimal reduction in energy consumption can translates into significant savings on the operational costs.

Furthermore, with construction of industrial plants involving the use of great quantities of building materials for structural elements the production, transport and placement of those elements can have a significant environmental impact factor. Moreover, when the useful life of an industrial building comes to an end all the materials used to build it are often turned directly into waste.

Some studies also have been investigating the relationship between lean construction and lean thinking. Marhani et al. (2013) investigated the literature review about the Sustainability through Lean Construction. Garza-Reyes (2015) deals with a systematic review of the state of the art literature in lean and green. Collin Koranda et al. (2011) investigated the Applicability of Sustainability and Lean Concepts to Small Construction Projects. Dhingra et al. (2014) in their research “Does lean means green” investigated potential applications of Lean and Green to help society make the transition to more sustainable societal patterns.

Furthermore, some other studies have been investigating the relationship between sustainability and industrial buildings. Abdelaziz et al. (2011) involves with the energy saving strategies in industrial sector while Alarcon et al. (2011) investigated a value function for assessing sustainability in the application to industrial buildings. This paper involves lean construction and sustainability in the industrial buildings. The research goal of it is to enhance the economic, social and environmental progress by addressing the need for

a continuous increase of value. The result of this effort is to deliver reduced environmental impact, energy consumption and construction waste while improving the quality, safety and health of the users.

2. Methodology

For this work a qualitative associational methodology has been employed that seek to identify the correlation between Lean Thinking and Sustainability in the Industrial Building design domain. The data collected represent a wide spectrum containing both original researches, aimed at identifying specific parts of sustainability as well as lean thinking with the addition of statistical data that solidify these relationships. The overall aim is to produce an analysis of the characteristics of the industrial buildings and their relationship with Lean Construction and Sustainability in the industrial building sector based on a study of a variety of different architectural approaches towards the development of the industrial shell and the tools in our disposal to address those questions.

2.1. Industrial building

An industrial Building's overall form is derived from functional needs rather than morphological choices. The architecture of the industrial buildings is essentially a "shell" with purely functional, safety and flexibility purposes.

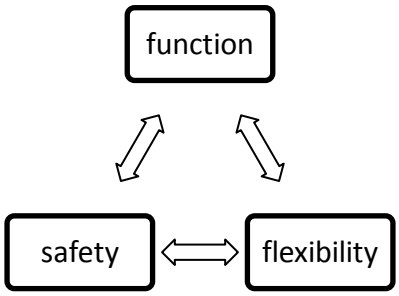

Figure 1. Basic requirements of an industrial building

The factors that have traditionally determined the architecture of industrial buildings are machine technology, functional organization and type of production. While at the same time, the level of construction technology, available building materials, current architectural idioms and the image that each business wishes to project materialize themselves in the final form. Those, therefore, determine the layout and morphology and the basic spatial structure of the industrial complex. The building shells traditionally follow the specifications defined by the production process, the equipment and the corresponding structural technology of the time. A basic feature of these buildings is simple geometry. Buildings consist of large, one-dimensional volume projection of their structural skeleton, being their basic morphological element and consist mainly single-storey large-area with a parallelogram structure made of steel or concrete with insulation.

Table 1. Characteristics of Industrial Buildings

CHARACTERISTICS OF INDUSTRIAL BUILDINGS
simple geometry/rectangular shape
one dimensional volume
short period of life
huge land
metal construction or concrete
large area of roof daylight from roof
continuous changes

The usual requirements that are being considered during the design stage of industrial buildings and warehouses according to their form and use are provided bellow:

- Required spaces for use, depending on the needs of the production line, specific material and machine handling requirements
- Flexibility of space use in current and future use
- Construction speed
- Environmental performance including maintenance requirements
- Aesthetics and visual alignment with the customer's corporate identity
- Acoustic insulation, especially in production facilities
- Access and security
- Sustainability
- Maintenance requirements and degradation / disposal planning after the end of the service life.

For a successful design of an industrial building all of the above need to be considered on a need basis for a particular type of industry and production line. As an example, the objective requirements for a distribution centre are quite different from those of a production unit. A general overview of the importance of the different design for common types of buildings (i.e. industrial, commercial and residential) has been presented (Steel building in Europe).

2.2. The industrial building and lean construction

An industrialized production process is characterized by vertical integration, a coordinated whole, from raw material collection to marketing, including research and development (Broberg, 1986). Each individual aspect is integrated into an overall process and it is noteworthy that according to the above identified

significant deficiencies come the understanding of industrial buildings planning processes capable to receive a lean supply chain and provide its shell (skin).

In the field of industrial production, many efforts have been made to increase the value of products and reduce waste of resources. The "Lean Production" is one of the major production systems seeking to reduce human effort, the time and space needed for the production process of investment and increase productivity: the requirement for almost half machines involves far fewer defective products and a growing variety.

Table 2. Eleven Principles of Lean Thinking by Huovila and Koskela (1998)

ELEVEN PRINCIPLES OF LEAN THINKING BY KOSKELA
Reduce the share of non-value adding activities (waste)
Increase output value through systematic consideration of customer requirements
Reduce variability
Reduce cycle times
Simplify by minimizing the number of steps, parts and linkages
Increase output flexibility
Increase process transparency
Focus control on the complete process
Build continuous improvement into the process
Balance flow improvement with conversion improvement
Benchmark

> *"Lean production is an integrated socio-technical system, whose main goal is to eliminate waste by simultaneously reducing or minimizing the variability that occurs at customer, supplier, and organic requirements"* (Shah and Ward, 2007).

The concept of Lean Construction is based on the application of Lean Thinking and Philosophy in the construction industry. Lean Construction aims at eliminating manufacturing waste by removing all non-added value activities. The construction sector is the sector of intensive use of resources and waste producer, which often has a significant impact on the environment (Pinheiro, 2003). This waste production must be taken seriously. According to Grohmann (1998), the amount of material and workforce wasting on three construction sites allows the construction of another identical project. There is waste of productivity and resources, which amounts to 33%. These wastes are reflected in labor costs, which can cause a 6% increase in total costs (Pinto, 1995). In this context, Lean Construction came to change the production management system in the construction sector. This concept aims at eliminating all types of wastes, such as costs, time, materials or equipment, in order to achieve a better final product, thus increasing the value of the customer.

3. Industrial buildings and sustainability

The growing environmental problems and the sustainable development strategy shape the new framework within which businesses will have to operate in the future. It is the logic of sustainability that sets new

growth rules in the light of serving current needs without depriving future generations. The basic ecosystem services that are currently cheap will become expensive tomorrow: from the initial supply chain processes (such as harvesting and collection of raw materials) to waste disposal, the required costs and product prices are bound to increase. A typical example is the lack and cost of clean water in many parts of the world (Bent, 2008). These costs affect and interact with the rest of the industry, resulting in the transformation of the operational framework of all businesses.

Industrial facilities are considered as "architectural elements", in a permanent interaction with the requirements for sustainability. The industrial buildings must meet sustainability requirements at multiple levels of reference: environmental, economic, social, security and industrial risk prevention, as well as appropriate architectural expression. The concept of sustainable development, which is considered politically correct and enjoys wider social impact, facilitates the integration of these design criteria into construction activities. As a result, there is an urgent need to research systems that promote new knowledge for the development of sustainable manufacturing systems.

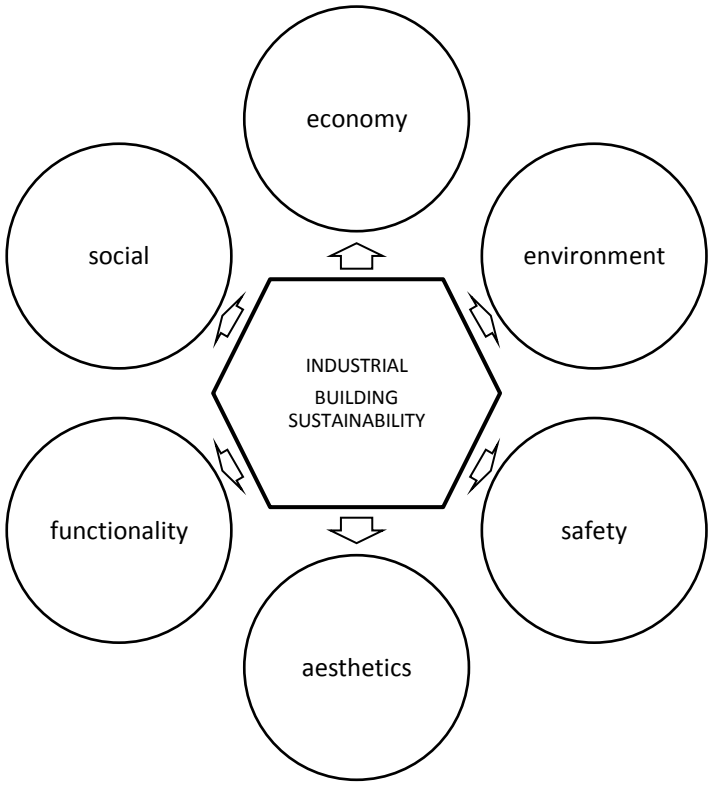

Figure 2. The environmental study scopes of an industrial building (Lombera and Aprea, 2010)

Building's life cycle can be divided into the following stages: concept, conception, design, construction, use, maintenance and demolition. Although higher energy consumption occurs during the use and maintenance

phases, interventions carried out at the design, design and design stages in order to reduce these impacts can lead to a better performing building and lower costs (Motta and Aguilar, 2009).

According to Lombera, J. and Aprea, G. the sustainability of industrial buildings must be based on four key criteria:

- location/orientation
- energy consumption
- the use of water
- the use of raw materials

Industrial activity consumes significant energy resources, handles raw materials, production processes and finished products. It is the energy consumed in the operation of such machinery (including the processes of transformation of raw materials) that often creates unfavourable environmental conditions for workers. In addition, the construction of industrial facilities itself involves the use of big quantities of materials for foundations, structure and partition walls whose production, transport and erection produces significant environmental impact. Finally, after the end of life cycle of an industrial building, construction materials and building blocks are often reduced to rubbish and a large part of it ends up as unclaimed waste.

This problem involves a variety of vectors requiring separate research and study. On one hand are energy saving measures in industrial buildings, techniques to reduce water consumption, dust and noise during construction and operation phases. On the other, measures to manage and minimize waste during construction and demolition and finally, measures to achieve a higher degree of reuse and recycling of materials.

4. The benefits of sustainable building principles

The built environment exerts tremendous pressure on the ecosystem, human health, and the economy. By adopting green building strategies, we can maximize both economic and environmental performance. Green building methods can be integrated at any stage of the building's lifecycle (design, construction, renovation, demolition). However, the most important benefits can be obtained by adopting an integrated management method from the early stages of programming. Green buildings have environmental, economic and social benefits (Lombera and Aprea, 2010):

- Protect biodiversity and protect ecosystems,
- Improve the quality of air and water,
- Minimize waste,
- Maintain and restore natural resources.

Financial benefits are also there with operating costs being reduced, improvement of productivity, optimisation of the economic life-cycle performance and green products and services provisions. At the same

time, the comfort and health of industrial personnel are enhanced, the aesthetics evolve and the quality of life is generally improved.

Table 3. Benefits of sustainable buildings

Environmental Benefits	Economic Benefits	Social Benefits
• improving air and water quality • reduced energy and water consumption • reduced waste disposal	• Reduced operating costs • Maintenance cost • Increased sale price and rent	• improved user comfort and health • Reduced liability

5. Discussion

Lean Thinking leads to environmental, economic and social benefits. Sustainability in construction has as its objective the efficient use of resources in the design, construction and use of buildings with emphasis on resources related to the environment and user health. Therefore, energy use, natural waste, environmental impacts as well as the creation of a healthy and productive work environment are the focus of sustainability in the construction industry.

It is therefore important that the framework is being implemented that will fully adopt the production line necessities, conform to sustainability aspects, respect the environment and accommodate flexible usage.

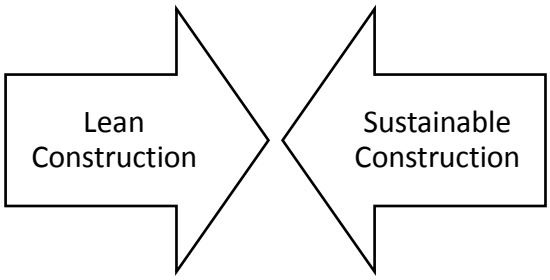

Figure 4. Connection Lean and Sustainable Construction

The principles of Lean Thinking in Construction are to minimize waste of material and time in an attempt to create and maximize added value. The concept of Lean Construction is similar to that of sustainable

construction, as both concepts attempt to minimize waste of resources during construction. Lean Construction is a constantly evolving concept that revitalizes the efficiency of the manufacturing process. In an industry that produces more waste than any other sector of human activity worldwide (Meadows, 2011). There are many points linking construction to sustainability as identified by their goals and priorities. For example, reducing waste is a common priority for both Lean Thinking and Sustainability (Koranda et al., 2012). Other points include environmental management, maximization of value, health and safety conditions, etc. (Hall and Purchase, 2006; Luther, 2005).

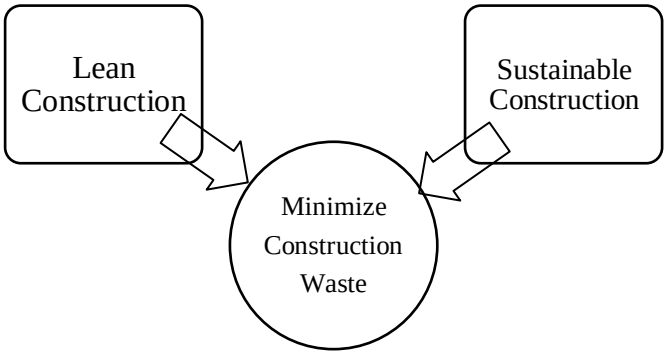

Figure 3. Basic Common scope of Lean and Sustainable Construction

Table 4. When Lean meets Sustainability

When Lean meets Sustainability	
Lean Construction	**Sustainable Construction**
Increase in Competitiveness Effective Resource Usage Improving Quality Cost reduction Efficiency Security Productivity Waste Minimization Risk Reduction Reduce harmful effects on the environment Prevention of pollution Waste Prevention Better relationships in the parties involved	

The authors separately approached and investigated the philosophy of lean construction and sustainable construction to come to the conclusion that indeed they share common goals. This observation lead in comparing and analyse them to establish the points of intersection. As a result of the above, the increase in competitiveness, effectiveness in resources usage, the improvement of the quality, cost reduction, efficiency, security, productivity, waste minimization, risk reduction, improvement of health and safety, reduction of the harmful effects on the environment, prevention of the pollution, waste prevention, and the better relationships in the parties involved, have been identified as points of intersection and has been summarised in the Table 4.

6. Conclusion

During the years that economy demands society to operate with reduced waste while increasing productivity, the design of sustainable industrial buildings is essential. The collaborative nature of Lean Construction and Sustainable architecture can provide a multitude of benefits both during the construction as well as the operation stages of an industrial buildings life.

The objective of Lean Thinking is the elimination of non-value adding activities. The construction sector has influence in the society, economy and environment while the industrial sector is one of the largest energy consumers. A big percentage of the energy consumption of the industrial buildings attributed of the operation of the buildings. The industrial buildings have to take into account seriously from the early stage the design according to sustainability. It is therefore concluded that it is only appropriate for the design of the industrial buildings to meet the objective of eliminating non-value adding activities taking into account the identified intersection points of the lean philosophy and sustainable construction.

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