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Day lighting: A Lean and Sustainable concept in Industrial Buildings

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Abstract: *The industrial sector is one of the largest energy consumers. Lean and Sustainable Thinking leads to environmental, economic and social benefits. Natural lighting is an effective strategy for sustainable construction based on Lean thinking principles providing important environmental and socioeconomic benefits. Much of the research revolves around the relationship between day lighting and office buildings, but few about the relationship between day lighting and industrial buildings. This article is an exploration between the relationship of day lighting with Lean thinking and Sustainable 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 day lighting, and how by successfully utilising those in unison can bring about great environmental, economic and social gains and benefits.*

Keywords: *Daylighting, Industrial Building, Lean Construction, Sustainability, Energy Consumption*

INTRODUCTION

In recent years, a significant change in the corporate environments has been recorded heralding a growing demand for corporate social responsibility as a result of global warming, resource depletion and other environmental issues. Environmental concerns attract more and more global attention and as a result, corporate environmental sensitivity is increasingly gaining importance.

Global climate change and the lack of critical resources such as energy and water are among the most important issues facing humanity in the early 21st century (Smalley, 2004). Population growth requires visionary research and development efforts that seek innovative solutions (e.g. innovative clean energy sources and economically feasible carbon capture strategies) to be implemented in the future (Pacala and Sokolow, 2004). According to the findings of the Vital Signs (2005) study prepared by the World Watch Institute (2005), the construction industry does indeed constitute a large contributor on environmental impact, as it consumes up to 60% of earth extracted materials, while the construction sector is responsible for 50% of the carbon dioxide emissions released into the atmosphere.

The industry of architecture, engineering and construction (AEC) is characterized as a great consumer of natural resources. It consumes 50% of natural materials and resources, 40% of energy, and accounts for 50% of total waste. It is, therefore, one of the key industries to move towards sustainability (Othman and Nadim, 2010). 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 reaches 31% (EIA, 2012).

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 be translated into significant savings on the operational costs.
This project aims at addressing 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.

Methodology

For this work, a qualitative associational methodology has been employed that seeks to identify the correlation between Lean Thinking and Sustainability in the Industrial Building design domain. The data collected represented a wide spectrum containing both the original research, 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.

Lean Construction and Sustainability in Industrial Buildings

The industrial building, or factory, is the shell around the area in which industrial production and storage activities are carried out. Industrial production is characterized by creating goods, and increasing their usefulness in meeting human needs.
The characteristics and usual requirements that are being considered during the design stage of industrial buildings and warehouses according to their form and use are provided in the tables 1 and 2 below:

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

Table 2. Usual Requirements of Industrial Buildings

Usual Requirements Of Industrial Buildings
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

Unlike other structures, industrial buildings require large layouts given the volume of machinery and products they need to house. The roof type is an important parameter in this type of building and occupies much of the surface as it is closely related to the production, natural lighting and ventilation of the building. The side windows in the building shell are insufficient to illuminate up to the depth of a factory that has wide interior space. Therefore, natural light entering through openings on the roof is more effective. An industrial building is usually one-storey and tall. Due to its height, the upward air currents cause thermal stratification, and the large surface of the shell also causes a large heat loss and gain.

For a successful design of an industrial building, all of the above are needed to be considered on a need basis for a particular type of industry and production line.

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.

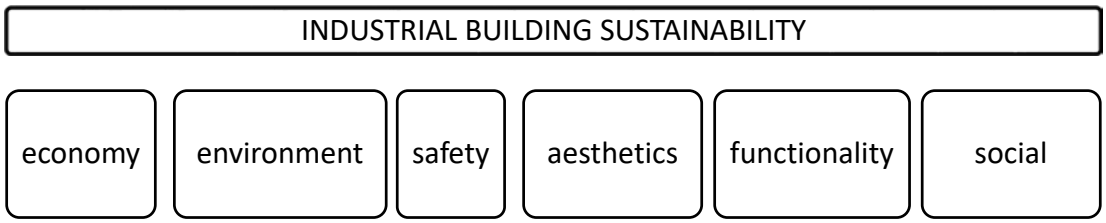

Figure 1. The environmental study scopes of an industrial building (Lombera and Aprea, 2010)

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).

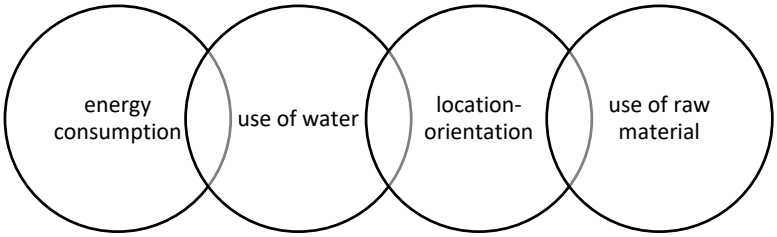

Figure 2. Four key criteria of sustainable industrial buildings according to Lombera and Aprea (2010)

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). 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.

The built environment exerts a tremendous pressure on the ecosystem, human health, and 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).

Financial benefits are also there with operating costs being reduced, the improvement of productivity, the 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.

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.

Daylighting in Industrial Buildings

Natural light not only creates an interesting, ever-changing environment that cannot easily or economically be achieved by artificial lighting, but also offers significantly reduced electricity consumption for lighting and increases productivity (IESNA, 2000). Natural light increases productivity by 10% but also reduces errors by 30% (ILO, 2014).

On the workers' side, under-lighting at the workplace can lead to fatigue, headaches, anxiety and accidents. On the other hand, over-lighting can also cause health and safety problems. Both situations are unacceptable as they can lead to work errors, poor quality of the final result, and low productivity.

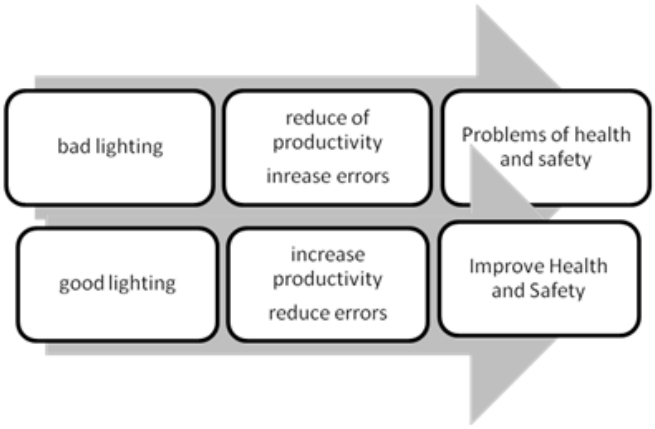

Figure 3. Effects of good and bad daylighting

Recent studies have shown that there is a correlation between lighting, performance and user/occupants' health. Light provides visual information but is also a powerful regulator of our circadian rhythm and many other non-optical functions, such as alertness, concentration and cognitive performance (Vandewalle et al., 2009).

Daylighting and Sustainability

According to the International Energy Agency (IEA, 2012), electricity consumption for artificial lighting reaches nearly 20% of the global electricity consumption, more than the annual total of nuclear power generation worldwide (McSmith, 2006). In the construction industry, electricity consumption for artificial lighting accounts for around 11% of energy use in residential buildings and 18% in commercial buildings (EERE, 2011), producing billions of tonnes of coal each year. The ever expanding world electricity consumption for lighting is expected to double in the future, with carbon dioxide emissions rising even further.

Sustainability is promoted in the construction industry as an energy saving feature to reduce environmental impact. However, the energy use of artificial lighting cannot be reduced unless the intensity of the artificial lighting is lowered or fully de-energized according to the interior levels of natural lighting (Leslie, 2003). A properly configured natural lighting system can reduce lighting consumption, while it can even further reduce cooling loads of indoor equipment. The reduction of artificial lighting consumption saves an additional 10-20% of the energy use of refrigerant loads (Ander, 2016). The implementation of natural lighting strategies contributes to reducing the consumption of artificial lighting, with a direct effect on the reduction of carbon and greenhouse emissions, along with lamp consumables and maintenance. In many commercial or social welfare buildings, total energy costs may be reduced by one-third (1/3) with the optimal integration of natural lighting strategies (Ander, 2016).

But as much as natural light is of good quality and superior, its very nature makes it particularly difficult to use without the proper study of application, and should include elements of optical comfort and thermal gains. The study of the elements and characteristics of natural light and its integration into an integrated indoor lighting system is the key to achieving appropriate, comfortable and energy efficient systems (Levy et al., 2011).

Sunlight is the most effective passive solar strategy in virtually all types of buildings because it reduces two of the largest energy needs of a building, the need for electrical lighting and the need for cooling. It is a fact that with the use of artificial electricity, large amounts of heat are generated in buildings, which create the increased need for cooling.

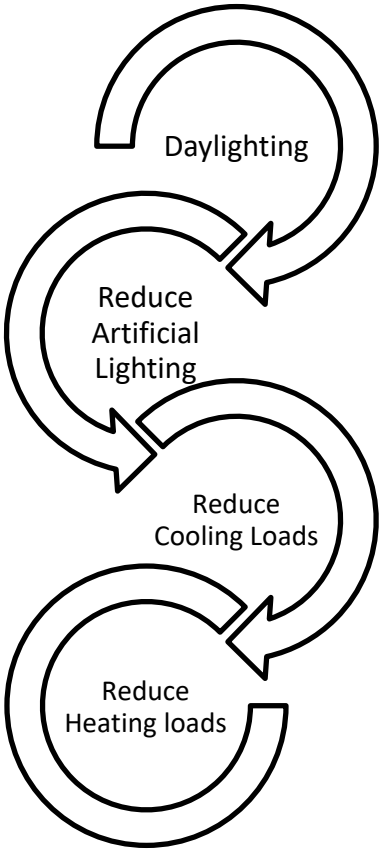

Figure 4. Energy Savings through Daylighting

According to the Illuminating Engineering Society of North America (IESNA), the use of natural lighting can reduce up to 30% of the amount of electricity consumed for indoor lighting. However, the overall energy efficiency of windows is also dependent on the thermal effects (e.g. solar gains and heat losses through glass) and in relation to the production of heat from artificial lighting systems.

An effective lighting design maximizes the use of natural light to meet the required lighting levels, thereby minimizing installed light loads and lighting consumption, thereby reducing internal heat gains (Bell and Burt, 1996). Therefore, the natural lighting strategy significantly influences the requirement for mechanical ventilation and air conditioning. The additional capital costs for improving natural lighting should be offset by savings in operating lighting costs and capital costs and operating costs for mechanical ventilation or air conditioning to remove the heat it produces.

Results and Discussion

An essential part of Lean Thinking is finding simple and comprehensible ways to achieve more with less. The sun is an inexhaustible source of energy and its most common and effective architectural use is to illuminate the interiors of the buildings. At the same time, passive solar heating systems - in which the building collects, stores and distributes heat load - are typical examples of absolute identification with the Lean Thinking and Philosophy with typically more upgraded solutions than active solar systems, the panels of which are added to the building with all requirements for liquids, pumps, thermostats and other systems for their operation.

Figure 5. Common points between daylighting and lean

Natural Lighting provides a number of economic, environmental and social benefits. Harnessing those benefits of the natural lighting is the main goal of Lean thinking. Some of them are visual comfort, increased safety, reducing work-related accidents, improving users' health, increasing productivity, and improving efficiency. While reducing energy consumption, it reduces pollutants, which in turn reduces the environmental pollution and reduces the life cycle cost of a building.

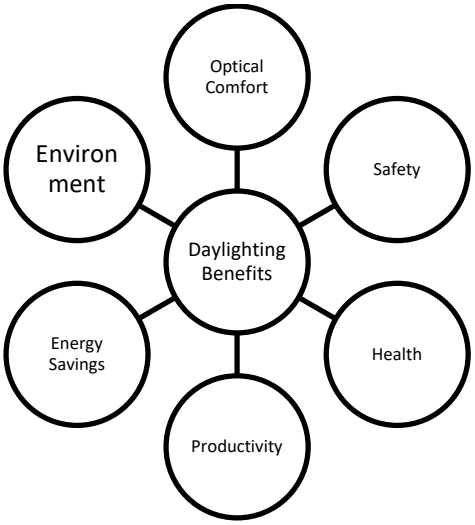

Figure 6. Some of the daylighting benefits in industrial buildings

It is a holistic approach that can provide hidden reductions in the life cycle cost of a building. For example, using natural light against artificial lighting promotes the reduction of thermal loads and hence reduces the required cooling load with a direct effect on mechanical equipment needs. While reduced machinery involves lower initial costs reducing waste, lean thinking emphasizes the reduction of waste that exists in the processes used for both design and construction. The emphasis is on producing products that are valuable to the customer, eliminating activities that are defined as wasteful.

During the years that economy demands societies to operate with reduced waste while increasing productivity, the design of lean and 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 at the operation stages of an industrial building's life.

Use of Natural light is an effective strategy for sustainable and simple construction as it improves visual comfort, productivity and health. The increase in natural lighting systems offers energy savings of up to 20-30% of the total energy a building consumes. In addition to the real cost and economic benefits of natural lighting through reducing energy consumption and maintenance of the lighting system, one must think about

the fact that with the right lighting design one can significantly improve performance and create a healthier indoor environment.

Moreover, Natural light helps with the reduction of the overall environmental impact since it reduces pollution, needs no resources for maintenance and requires no energy. There is also the social dimension of cost and natural lighting, that is, in the long run, as artificial lighting decreases and natural lighting increases, we are leading to a more energy-saving economy that brings profit to society as a whole.

Therefore, designing industrial buildings with a view to simple construction and sustainability is an essential requirement, and that is a proper design of industrial buildings based on natural lighting.

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