Lean Thinking into the modular construction of industrial buildings. Identifying the role of daylight

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Abstract. The necessity of energy equilibrium in industrial building stock must be addressed at design level in order to optimise use of materials without jeopardising the functional outcome. To do so effectively, the designer should incorporate a light use vs availability balance that will harness as much natural light resources as possible without creating unfavourable conditions due to over-exposure and thermal gains/losses. This work is an exploration between the relationship of sustainability with Lean thinking in the backdrop of sustainable and Lean construction. Exploring the benefits of lean and sustainable construction is about exploring how one can bring about great environmental, economic and social gains with the minimization of energy use, natural waste, environmental impacts as along with the creation of a healthy and productive work environment are the focus of sustainability in the construction industry. In effect answering how Daylight and Lean Thinking Principles can lead to optimizing Industrial buildings in terms of design and execution.

1. Introduction

Currently, one can observe a significant change in corporate environments and decision making. The new dawn of corporate social responsibility demand from end users and stakeholders alike as a result of pressing socioeconomic [1] and environmental issues [2]. In this climate environmental concerns attract more and more attention and become central parts in the global development agenda. Work presented in the past from [3] has irrefutably presented the great contribution of the construction industry in terms of environmental impact demonstrating its insatiable demand for earth extracted materials that reaches 60% while being responsible for 50% of the man-made CO_2 emissions in the atmosphere. Despite the fact that a considerable amount of research has taken place in the past in terms of a building's environmental and pollution footprint, as this is determined in terms of air, noise, energy and water consumption amongst others, less attention was paid to the effect the building design and construction process has in that regard.

Additionally, work in the field has shown that the industrial sector is one of the major consumers of energy with data from 2011 showing that the sector was responsible for 26% of the total energy consumption according to [4] while in the US it represents an even higher proportion of 31% [5] with only 7.5% of that energy coming from renewable sources of energy in the same year [6]. Research in different sectors in the US identified a "waste" of energy on non-productive activities of 15% with the majority of that (80%) being directly or indirectly attributed to lighting and air conditioning [7].

Tsangrassoulis et al. [8] has undertaken research in the past that aimed at examining a hybrid daylighting system while Doulos et al. [9–11] investigating the relationship that hybrid dimming and daylighting systems have while Kontadakis et al. [12] focused on the impact of active sunlight

redirection systems for daylight. On top of the above, a variety of studies have been undertaken on the study of daylight systems and devices inside different building types and the effects those have [13, 14] providing ample of evidence and scope for the incorporation of those elements in a holistic approach to the design paradigm. In that effect daylight can be an effective sustainable construction strategy based on Lean thinking principles. This can provide important environmental and socioeconomic benefits with the reduction of the overall environmental impact due to reductions in emissions. Furthermore this strategy requires no significant maintenance resources for and is a passive form that requires no additional energy.

The above all signified the importance of such work in the field of conceptual design and construction where the synergy between those different aspects of modular and lean construction principles along with the importance of maximizing the utilization of available natural resources such as lighting and how that can lead to the identification of optimal solutions in terms of resource waste. This paper aims at addressing the environmental, social and economic progress by ensuring a continuous increase of embodied added value in the Architecture, Engineering and Construction (AEC) industry by providing a framework for the synergy between lean construction and sustainability in the industrial buildings in terms of modularity and daylight requirements. As a result, delivering not only reduced energy consumption, environmental impact and waste for the design and construction process but also improve the quality, safety and health aspects for the end users.

Due to the particular needs of an industrial envelope and estate in terms of big, unobstructed areas and adequate work light conditions without jeopardizing sustainable construction and ethical footprint it is becoming important for the stakeholders to explore industrial construction, sustainability and their relationship. With the implementation of Lean Thinking principles in design and construction one can attain benefits in environmental, economic and social terms with the elimination of non-value adding activities and processed in terms of design and implementation. Additionally, the apparent economic and environmental benefits of Lean Thinking compound to the potential social improvement aspects that such an approach can have with its objective being the efficient use of resources in the design, construction and use of buildings putting a major emphasis on the resources necessary to improve the overall environment and user health while minimizing waste. A series of studies have investigated the relationship between lean construction and Lean Thinking (LT) [15] investigating the review of the bibliography about the Sustainability through Lean Construction (LC) while others [16] dealt with a more systematic review of the state-of-the-art literature in lean and green.

2. Methodology

The project will use qualitative research methods. The qualitative approach is considered an effective method for conducting extensive review and identifying research gaps. A systematic approach will be used to determine the characteristics and requirements of industrial buildings. The aim is to analyse the characteristics of industrial buildings and the relationship between LC and Sustainability for optimisation of the corresponding building type. A qualitative research to identify the key components that link modular construction to the above will be conducted. This approach aims to identify similarities between these issues. This method will drive to recognition of a tool that will follow these common values and optimize industrial buildings in relation to Lean thinking.

The qualitative approach is an exploratory research that focuses on the collection of secondary data collected from sources such as published articles, books, magazines and web portals. After the collection of the data will follow summary, synthesis and comparison of the information obtained in order to develop critical knowledge about the investigated area and address the research questions.

3. Industrial Buildings

An industrial building is designed according to its functional needs despite morphological choices. Their main feature is the simple geometry. Their design is a "shell" with purely functional purposes, reasons of security and flexibility, follows the prevailing one construction technology, available building materials and project the image of the business. As a point to note, the buildings consist mainly of one-dimensional volumes with rectangular construction.

Table 1. Characteristics of Industrial Buildings and Requirements during the design Stage.

Characteristics of industrial buildings	Requirements during the design stage of industrial buildings
Construction of metal or concrete	Aesthetics and customer's corporate identity
Continuous changes	Flexibility in current and future use
Land	Maintenance Requirements
Large roof	Needs of the production line
One dimensional volume	Specific material
Shape (Rectangular / simple geometry)	Speed of construction
Short life cycle	Sustainability / Environmental performance
Sufficient penetration of Daylight	

The concept of LC is based on the application of LT and Philosophy in the construction industry. The construction sector uses intensively resources and produces waste with a significant impact on the environment [17]. In the same vein, Grohmann [18] showed that the amount of material and workforce wasting ranges anywhere up to 30% of the actual construction itself in a world that suffers from the lack and cost of clean water. Furthermore, [19] has shown the reflection of such waste in labour costs, which can cause a 6% increase in total costs. Therefore, LC positions itself at the right place to effect change in the production management system of the construction sector eliminating all types of wastes.

Modular Construction buildings are created and controlled in a factory environment, which allows the high quality of finishing and the use of different materials such as wood, steel or concrete [20]. Some of the key features of Modular Construction are the safety of construction, the reduction of construction time, the reduction of waste, the flexibility enabling the creation of many types and the reuse for various types of buildings of any size. Historically, the design of these structures was done with simple lines and simplicity. In recent years, Modular Construction has evolved into a much more complex and aesthetically acceptable set which not only meets the basic needs of the user but can also allow constant change depending on the needs that arise. Yu et al. [21] identified Modular construction systems as an agglomeration of 3 discreet ideas, those of prefabrication, standardization, and dimensional coordination. One of the most important aspects of modular products and their implementation is the potential for effective flexibility and reduced process complexity [22].

One of the most important benefits of Modular Construction is the rapid construction and the short time between the beginning of the construction project and the delivery of the final project to the customer [23] In addition, the risk of delays due to extreme weather conditions is minimized [24]. Finally, Modular Construction can and does save about 40% of construction time compared to traditional techniques factory-built in a controlled environment [24, 25]. Such a method of construction offers various advantages compared to the conventional way of on-site construction such as the reduction of project time, but also the increased quality characteristics. Therefore, standardization can be considered as a process with multiple advantages throughout the manufacturing process. Modularity offers improvements to the construction of a building throughout its life cycle, from development to resale [26]. The use of Modular philosophy in construction is a method of value management, where internal (production) and external (customer) needs are balanced [27]. It enables construction flexibility but also reduced complexity in the construction process [22].

Concluding, Modular Construction is the most effective way to reduce waste in the construction industry. The significant reduction in materials but also time is what plays such an important role in designating this way of construction as Sustainable Building. The above in combination with the Modular design form allows, under appropriate forecasting conditions, the deconstruction of the structure in the future and the reuse of these elements in new constructions outside the space [20]. There are multiple benefits stemming from the use of modular construction. Nikmehr et al. [28]

identified those in terms of waste minimization while Boyd et al. [29] focused in the improvement recorded in the overall quality. However, the role of daylight and how it can be adapted in the Modular Construction with a beneficial way hasn't examined further.

4. The role of Daylight

Natural light has many benefits for humans and the environment. Increases productivity, reduces errors while reducing electricity consumption for lighting. At the same time, it creates a pleasant environment that cannot be easily or economically achieved with artificial lighting [30]. Research says that productivity can be increased by 10% and errors can be reduced by 30% [31]. Studies correlate lighting with performance and health of users. Misuse of natural light can lead to poor quality of work, low productivity and increase of errors as a result the creation of a waste. Low lighting in the working plane can lead to employee fatigue, headaches, stress and accidents. In addition, excessive lighting can also cause health problems. Light regulates our circadian rhythm, our alertness, concentration and cognitive performance amongst many other non-visual functions [32].

Research shows that 20% of world electricity consumption comes from electricity consumption for artificial lighting [33], a number that exceeds the percentage of total annual nuclear energy production worldwide [34]. In addition, electricity consumption in the construction sector for artificial light represents about 11% of energy use in domestic and 18% in commercial buildings [35], generating billions of tons of carbon each year. Global electricity consumption for lighting will continue to expand and is expected to rise in the future, with CO_2 emissions to be doubled and even more.

Although sustainability is promoted to save energy and reduce environmental impact, the use of artificial lighting cannot be easily reduced [36]. Finding a solution of a suitable natural lighting system could reduce the consumption of lighting, while it could reduce the cooling loads of the internal equipment as much as possible. By achieving a reduction in the consumption of artificial lighting, an additional 10-20% of the energy use of refrigeration loads can be saved [37].

By applying natural lighting strategies, the reduction of the use of luminaires can be achieved, with a direct reduction of greenhouse emissions, as well as with consumables and with the maintenance of lamps. Incorporating lighting strategies can reduce the total energy cost in buildings such as commercial or social welfare by one third (1/3) [37]. Furthermore, daylight provides many benefits, but this requires an application study that includes elements of visual comfort and thermal gain. Proper study of the daylight characteristics and its integration into the building design will lead to the achievement of appropriate, comfortable and energy efficient systems [38]. Proper use of natural light can reduce the two main consumers of a building, electric lighting and cooling as the misuse of luminaires excessive amounts of heat in buildings, which create an increased need for cooling. The use of daylight can reduce by up to 30% the amount of electricity consumed for lighting [30]. The daylight harvesting in order to be efficient needs to be designed in a way that meets the required lighting levels using photosensors [39].

While the part of the daylight in industrial building is crucial, its impact in modular building hasn't yet been correlated (Figure 1). As an example, the opening dimensions chosen to be implemented should conform to multiparametric criteria and ensure light uniformity as described in EN 12464 while maintaining an economic profile in terms of construction while making optimal use of available daylight for the examined area where a modular building can be placed (Figure 2).

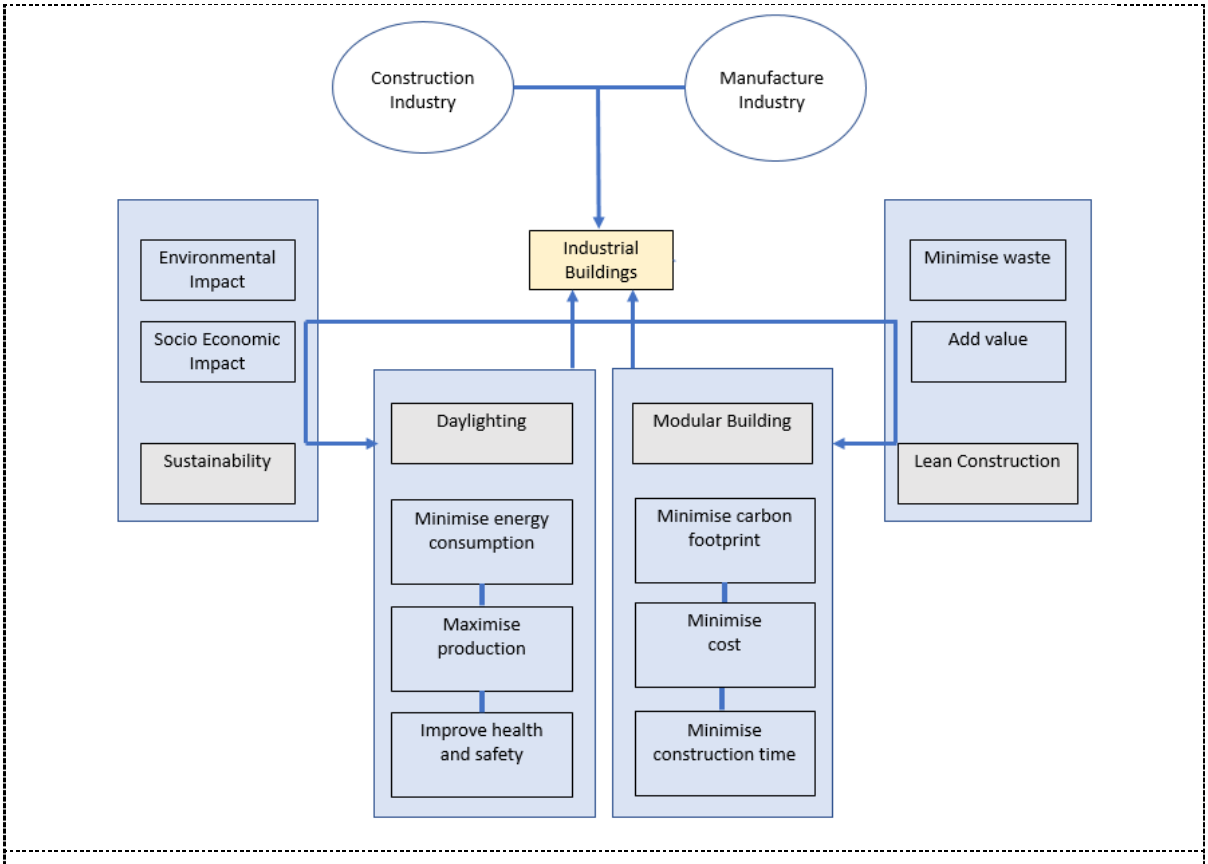

Figure 1. Path of interdependency between Sustainability, Lean Construction and Daylight.

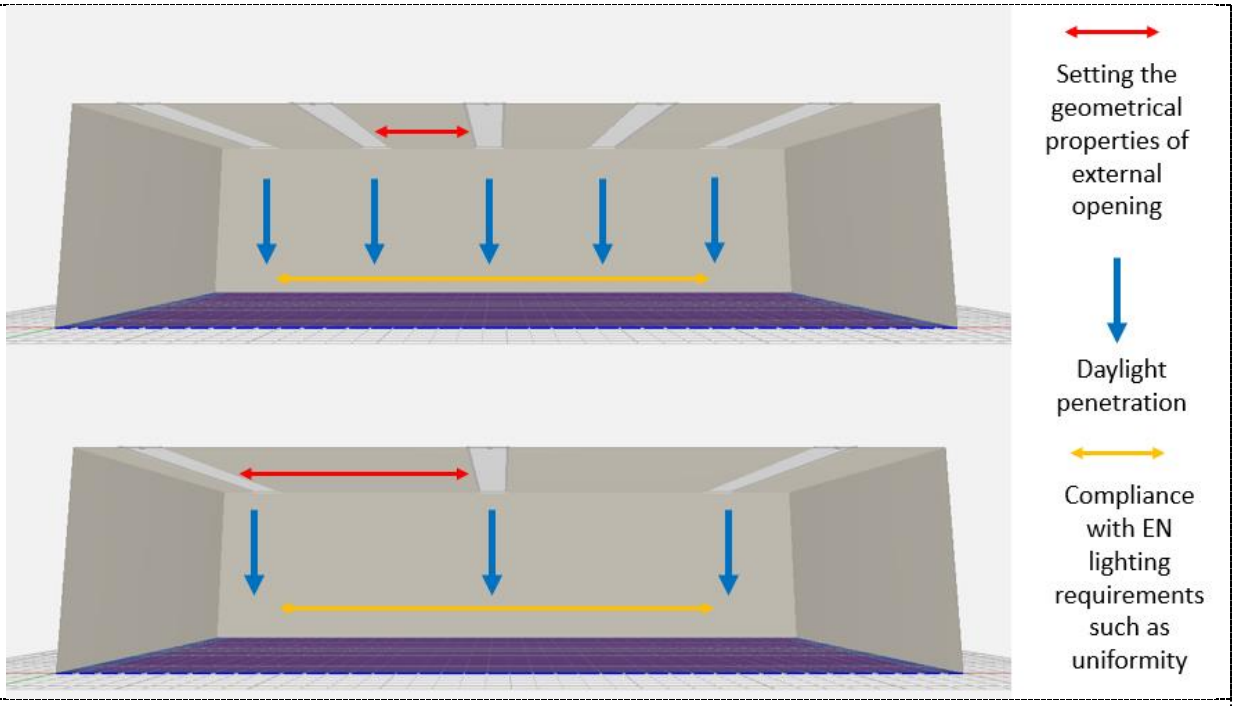

Figure 2. Setting the geometrical properties of external opening for a modular construction a) concerning the most beneficial solution having compliance with European Norm lighting requirements and b) considering the area of the modular building for the corresponding daylight data.

5. Discussion and Conclusions

Lean Thinking provides multiple benefits in terms of the environment, the economy and social aspects of a project while sustainability has as an objective the efficient use of resources in the design, construction and use of a building. Therefore, the emphasis on resources related to the environment and user health becomes the apparent focus of sustainability in the construction industry. In that regard, as the principles of Lean Thinking in Construction are those of minimizing waste of material use and time allotted to maximize added value the similarities between the concepts of Lean Construction and those of sustainable and modular construction become apparent. Nowadays industry produces more waste than any other sector of human activity worldwide [40]. The above in combination with the Modular design form allows, under appropriate forecasting conditions, the deconstruction of the structure in the future and the reuse of these elements in new constructions outside the space [20].

For the purpose of this work the authors approached the concept of lean, modular and sustainable construction in a manner that allows meaningful conclusions to be drawn comparing and analysing them for intersection points to be identified. In that respect, multiple environmental, economic and social benefits of daylight have been identified and the ability of Lean thinking to aid in harnessing those benefits has been explored. Therefore, the ability of Natural light to influence visual comfort and improving users' health have been highlighted with the relevant increases in productivity, and improvement in efficiency being directly affected. Furthermore, the overall reduction in energy consumption, directly contributes to the reduction of pollutants which in turn both directly and indirectly affect the environmental footprint and affects the whole life cycle cost of the building in question. It has therefore been shown that the use of daylight is an effective strategy for sustainability with savings in the order of up to 20-30% of the total energy demand of a building in addition to the real economic cost and benefits. As such it presents a holistic approach that provides multiple benefits to the stakeholders and end-users alike with reductions in the overall thermal equilibrium and specially the cooling load while reducing the initial costs of HVAC and reducing overall waste.

As the cornerstone of Lean Thinking philosophy revolves around identifying ways to achieve more with less, not taking advantage of a resource like the sun and the Natural daylight that it provides in abundance would not play strongly in its favour. Therefore, utilising the sun as a source of illuminating a building's interior illuminate or for collecting, storing and distributing heat load through the use of technologies such as passive solar heating are typical examples of Lean Thinking and Philosophy and must be exploited to achieve our sustainable future goals in construction. Natural Lighting has been the point of application of Lean Construction in the present research with the aim of this study of a methodology that optimizes industrial buildings through Natural Lighting in various areas.

6. References

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