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Opportunities and Challenges of Green-Lean: An Integrated System for Sustainable Construction

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Abstract: Although the two concepts of lean and sustainable construction have been developed due to different incentives, and they do not pursue the same exact goals, there exists considerable commonality between them. This paper discusses the potentials for integrating the two approaches and their practices and how the resulting synergy from combining the two methods can potentially lead to higher levels of fulfilling the individual goals of each of them. Some limitations and challenges to implementing the integrated approach are also discussed. Based on a comprehensive review of existing papers related to sustainable and lean construction topics, the commonality between the two approaches is discussed and grouped in five categories of (1) cost savings, (2) waste minimization, (3) Jobsite safety improvement, (4) reduced energy consumption, and (5) customers' satisfaction improvement. The challenges of this integration are similarly identified and discussed in the four main categories of (1) additional initial costs to the project, (2) difficulty of providing specialized expertise, (3) contractors' unwillingness to adopt the additional requirements, and (4) challenges to establish a high level of teamwork. Industry professionals were then interviewed to rank the elements in each of the two categories of opportunities and challenges. The results of the study highlight how future research can pursue the development of a new Green-Lean approach by investing in the communalities and meeting the challenges of this integration.

Keywords: lean; sustainable construction; integration

1. Introduction

Sustainable development has been able to establish its essentiality in recent decades due to the raised awareness about the alarming environmental challenges such as global warming, air and water pollution, and depletion of natural resources [1–5]. The strong ties between environmental concerns and urban development as one of the primary generators of material wastes and consumers of water and energy have also been recognized by many governments as well as construction industry professionals and decision-makers. This explains why sustainable construction practices are now enshrined in government policies [6,7].

Sustainable construction impacts how facilities are designed, constructed, maintained, renovated, or demolished. It is based on providing a set of sustainability requirements that need to be addressed throughout the lifecycle of facilities. The adaptation of green practices in the construction industry has been increasingly growing due to the rise of environmental concerns, as well as green buildings' success in enhancing the quality of life, providing desirable natural and social environments, lowering energy costs, and also because of governmental supports.

Lean construction is a fairly new approach, rooted in the manufacturing industry, that focuses on minimizing activities that do not lead to generating value for the project owner. In this context, non-value-adding activities are considered as wastes. The term ‘waste’ in lean construction terminology has a broad meaning that includes multiple categories, as shown in Table 1. By minimizing wastes, lean construction pursues maximizing the generation of value for the owner. Studies strongly support the multiple advantages of the application of lean in construction projects [8–10]. These advantages will be discussed in detail in the following sections.

Table 1. Types of wastes in the context of lean construction.

Waste Category	Definition	Examples
Defects	Wastes due to failing to meet the scope/owner’s expectations/comply with the project’s internal and external requirements	design errors leading to rework
Overproduction	Waste of resources for producing more than what is required or needed	Preparing too many framework sets for concrete pouring
Waiting	Waste generated from stopping an activity to let another (dependent) activity finish first	Loader waiting for a truck to return to loading spot
Non-utilized skills/capabilities	Underutilization of the project player’s knowledge, skills, and talents, as well as the capabilities of equipment or waste of money due to paying extra for hiring/using individuals/machines that offer capabilities that cannot be utilized	Paying extra for a highly productive scraper and not fully using its capacity
Transportation	Wastes rooted in the unnecessary movement of tools, materials, and equipment.	The slow movement of the equipment due to the poor quality of access roads
Inventory	Wastes of materials	Ordering extra materials and not using them
Motion	Unnecessary movement of individuals on the project site	Excessive movement of craftspeople to grab their tools, resulting from poor site layout
Over-processing	Waste of resources caused by exceeding what is required by the defined project scope	Spending too much time on the aesthetics (beyond what the scope complies) that will result in delays

Lean construction, in brief, has been increasingly adopted for its contribution to making the projects more profitable [11–14], enhancing the quality [15–18], and improving customer satisfaction [19–24]. While the focus of lean construction is not sustainability, it has significant impacts on improving the sustainability aspects of construction projects. The considerable commonalities between the two approaches create the potential for integrating them. In order to do so, an extensive understanding of the two approaches’ focus and their drivers is required.

1.1. Main Focuses of Sustainable (Green) Construction

Sustainable development aims at environmental protection, social well-being, and economic prosperity [25]. As shown in Figure 1, the built environment is responsible for a significant share of critical environmental concerns. Sustainable construction is one of the major players of sustainable development that aims at minimizing the negative impacts of construction on the aforementioned triple bottom-lines of sustainability [26–28]. This is based on a comprehensive approach that covers the lifecycle of a facility and applies multiple strategies and practices, which focus on minimizing and optimizing energy, water, material, and resource consumption [29].

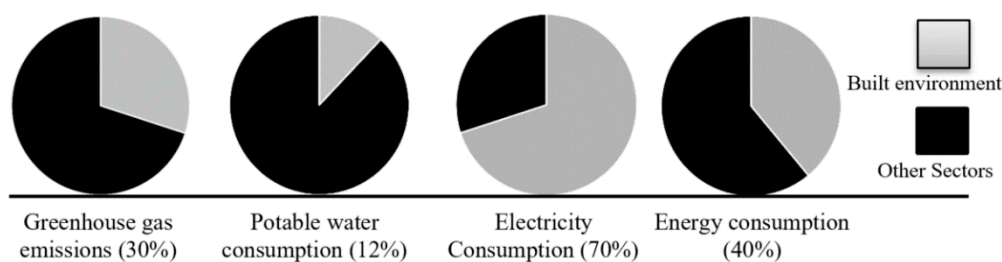


Figure 1. The share of the built environment in four environmental concerns.

1.2. Main Focuses of Lean Construction

Lean construction aims at minimization of wastes and transforming it to value, which is what the customer is willing to pay for [30–32]. To make this happen, it utilizes a variety of techniques such as just-in-time (JIT) [33,34], total quality management (TQM) [35,36], total productive maintenance (TPM) [37], supply chain management [38], and effective human resource management [39–41]. In the lean concept, wastes are not limited to construction material; they include all sorts of inefficient use of labor force, equipment, and other resources in the project [42].

1.3. Comparison of the Drivers of Green and Lean Construction

An essential parameter in integrating the two concepts of green and lean is understanding their drivers. Integration can be focused on meeting the requirements of similar drivers. Table 2 lists the drivers of the two approaches based on the literature [43–51]. As can be seen, there exist significant communalities between the drivers of two approaches.

Table 2. Commonalities between the drivers of sustainable and lean construction.

Sustainable Construction Driver	Lean Construction Driver	Connection/Community /Common Contribution
Mitigating the negative impacts of the built environment	Minimizing waste generation and transformation of waste to value	Protecting the environment
Contributing to the user's health, comfort, and productivity	Reducing the costs for the owner by maximizing the generation of value	Enhancing customer satisfaction
Reducing the operation costs of the facility	Reducing construction costs	Lowering costs
Increasing property value and rate of occupancy	Reducing project delivery duration and creating brand integrity for the contractor	Contributing to the developer's reputation
Setting rules, standards and legislations serving sustainability	Setting new approaches based on maximizing collaboration in project delivery	Transforming the traditional practices of construction

In addition to the drivers of the two approaches, their impacts have significant overlaps. As was mentioned above, sustainable construction aims at minimizing the adverse effects of construction on the triple bottom-lines of sustainability. Lean construction has been shown to have positive impacts on all the sustainability bottom-lines [52,53]. From the environmental standpoint, lean minimizes material wastes and efficient use of resources and lowers the negative impacts of construction (dust, noise, water, pollution, etc.) by shrinking the construction process duration. Lean's positive effects on social bottom-line are primarily due to reducing the rate of job accidents and personnel injuries and improving the quality of the constructed facilities and users' satisfaction. Finally, reducing the project cost is the main benefit of lean on the economic bottom-line.

2. Background

Both green and lean construction are relatively evolutionary philosophies that have been able to establish themselves as successful practices. The idea of combining the two methods has been studied by a limited number of studies [54,55] focused on the waste minimization concept as a linkage between the two approaches in the Midwestern United States and interviewed with the construction

professionals in this region to identify the primary sources of wastes. Reference [56] introduced a conceptual framework for the implementation of the lean approach in sustainable construction by studying different linkages between lean and sustainability.

The concept of lean has roots in the Japanese manufacturing culture and was first applied in construction by Koskela, who considered construction as a flow process and tried to find out the problems that would interrupt the smooth flow of construction activities [42]. The study by [6] verifies extensive applications of lean philosophy in construction in many parts of the world such as the UK [57], Singapore [56], Brazil [23], The Netherlands [58], and South Africa [59].

3. Research Methodology

As was explained above, there is considerable potential in integrating the green and lean approaches in construction. Yet, this integration has not been established systematically in the construction industry. Even in projects that pursue green certificates and, at the same time, are constructed using lean practices, the project team has a separate view of fulfilling the requirements of each of the two methods. This research investigated the potentials for actualizing this integration. Based on this, potential opportunities and challenges of this integration are discussed, and the results of interviewing construction professionals in each part are reported.

3.1. Potential Opportunities for Integrating Green and Lean Approaches

Based on the drivers and impacts of green and lean construction, the potential can be categorized into four significant common implications of the two approaches, which are cost savings, waste minimization, jobsite safety improvement, reduced energy consumption, and customer satisfaction improvement. These categories are explained in the following sections.

3.1.1. Cost Savings

Reducing the costs has been shown to have a central role in motivating the industry players as well as the owners and investors in the construction industry. According to McGraw-Hill Construction, financial concerns are more than twice as important for the contractors when compared to environmental concerns [27,60]. According to the United States Green Building Council, green buildings decrease operating costs by 8–9%, increase total building value by 7.5% and increase the building occupancy rate by 3.5%. From the lean perspective, the application of target value design, which is one of the practices in lean, has been shown to cause a 15% reduction in the final costs of projects [61]. The existing synergy between green and lean concepts regarding cost savings is a significant potential for concurrent and integrated application of both practices in construction projects.

3.1.2. Waste Minimization

The construction industry is responsible for generating a high proportion of solid waste worldwide [1]. Sustainable construction practices have comprehensive requirements for the storage and collection of recycles as well as waste management during construction and demolition. One of the primary goals of lean construction is to minimize all types of wastes in the construction process. In the lean context, however, wastes go beyond material waste and include overproduction, rework to fix defects, unnecessary motions of laborers and equipment, and waiting time. In the meantime, there is a clear overlap in minimizing waste of materials in both approaches. Sustainable construction pursues waste minimization through reducing, reusing, and recycling wastes. Lean construction contribution to waste minimization originates from its focus on optimizing resource utilization. Based on this approach, materials are one of the primary resources on a project, and the waste of materials should be minimized through value stream mapping, pull approach (instead of push approach), enhancing material flow, and continuous improvement. The two methods target different waste minimization strategies and can potentially complement one another in terms of minimization of physical, i.e., material wastes.

3.1.3. Jobsite Safety Improvement

Accidents and injuries during the construction process are considered one of the most significant negative impacts in this industry. According to the report provided by [62], in 2015 and 2016, respectively, a total of 4836 and 5190 fatal occupational injuries were reported in the United States. In a study by [63], it was stated that “construction workers accounted for 1 in 5 on-the-job fatalities and 1 in 10 nonfatal workplace injuries and illnesses in 2004”. This significant portion of construction-related fatalities indicates the necessity of enhancing safety measures throughout the construction process. This is particularly essential from the sustainability aspect as workers’ fatalities have a substantial negative impact on the social well-being bottom-line. The application of lean practices has been shown effective in reducing job site accidents. According to a study by [64], accident rates in projects applying lean practices were approximately 7.85%, while in other projects it was 14.13%. The 44% lower accident rate is considered a massive accomplishment in the lens of sustainability. Improving job site safety when lean practices are implemented can be attributed to optimizing the workplace through layout and workstation optimization, which leads to a reduction in potential job hazards [65].

3.1.4. Reduced Energy Consumption

Sustainable construction has extensive policies to reduce energy consumption through various measures. From the efficient use of materials that will lead to savings in energy, which is required for the extraction, processing, and shipment for materials to utilizing natural energy in ventilation and lighting, sustainable construction attempts to reduce the use of non-renewable energy sources. Lean construction pursues the same goal mainly during the construction process of buildings. Lean techniques such as Kaizen, Six Sigma, and JIT focus on maximizing productivity [66]. Increased productivity is tied to a reduction in the energy demand for performing construction tasks. The approach integration can lead to less energy consumption starting from construction onto the operating life of a facility.

3.1.5. Customers’ Satisfaction Improvement

In addition to improved quality, both approaches can effectively contribute to customer satisfaction. One of the focuses of sustainable construction is providing a high level of comfort indoors, through optimizing natural lighting, enhanced ventilation, appropriate acoustics, and thermal comfort. Consistently, the goal of lean construction is to deliver value to customers [52]. As was mentioned previously, the value in the context of lean is what the customer is willing to pay for. The lean approach requires the construction team to look at all the construction tasks from the lens of the customer to deliver the project with the maximum possible productivity, speed, quality, and minimum wastes. Both approaches, therefore, closely monitor the customer’s needs, and their integration can effectively synergize their impacts on customers’ satisfaction. In addition to improved quality, both approaches can effectively contribute to customer satisfaction. One of the focuses of sustainable construction is providing a high level of comfort indoors, through optimizing natural lighting, enhanced ventilation, appropriate acoustics, and thermal comfort. One of the overriding goals of lean construction is the delivery of value to the customers [52]. As was mentioned previously, the value in the context of lean is what the customer is willing to pay for. The lean approach requires the construction team to look at all the construction tasks from the lens of the customer to deliver the project with the maximum possible productivity, speed, quality, and minimum wastes. Both approaches, therefore, are closely tied with meeting the customer’s needs, and their integration can effectively synergize their impacts on customers’ satisfaction.

3.2. Potential Challenges to Integrating Green and Lean Approaches

As green and lean construction have been developed based on different purposes, there are potential challenges in their integration. Lean approach has roots in industry and is a production-based

management strategy [67], which is focused on the construction process. Sustainable construction goes beyond the building shell; it is not limited to the construction and extends to the lifecycle of a facility.

The construction industry, by nature, tends to rely on traditional methods, and resistance to change is a common challenge to apply new practices. After a comprehensive review of the literature and interviewing industry professionals, the challenges of integrating green and lean approaches were categorized into four main groups that are explained in the following. For maximizing the impact of this integration, these challenges should be considered and practical solutions for resolving them should be developed through further research and coordination of the experts of the two approaches.

3.2.1. Additional Initial Costs to the Project

While both green and lean construction are expected to lead to cost savings, compared with traditional project delivery, they require more initial costs. This specifically applies to the implementation of green practices, as they are tied to meeting a broad range of requirements such as using specific water fixtures, providing bicycle and green vehicles parking spaces, reducing energy consumption, and enhancing the indoor air, lighting, and thermal comfort quality to name a few. In the case of lean construction, higher initial costs are primarily attributed to the technology that is needed to apply lean techniques such as visualization, the pull approach, and the last planner system. It also requires having project managers who can perform six sigma's, 5S, or Kaizen techniques, which are commonly more expensive to hire. Financially related issues are considered one of the most common barriers to the implementation of lean construction. The cost-savings due to reduction in energy and water consumption cannot adequately compensate for the additional initial costs because facility owners who benefit from the savings are, in many cases, different from the investors who develop the facility.

3.2.2. The difficulty of Providing Special Expertise

Applying each of the green and lean approaches requires a comprehensive understanding of the goals, tools, and methods of implementation, management, and evaluation. This expertise can be provided through two options. The first option is hiring experts from the two backgrounds of green and lean who can effectively work together and contribute to one another. By hiring two project teams or project managers, this creates a potential for new challenges in planning, decision making, and utilizing resources on the job site. The second option is hiring a project team, and specifically a project manager, who is an expert in implementing both approaches. Construction professionals with these specifications are scarce, if not nonexistent. Additionally, selecting the contractor from a smaller pool of qualified contractors who are familiar with both approaches will limit the owners' options. Furthermore, it leads to less competitive bidding and potentially higher costs for owners.

3.2.3. Contractors' Unwillingness to Adapt the Additional Requirements

Both sustainable and lean concepts are broad, and each of them adds a large number of requirements specifically during the construction process of a facility. Considering the nature of construction projects, which are long-time endeavors involving a unique combination of many tasks, risks, unpredictable environments, and project players, there is a tendency to simplify the process to make it more controllable. Contractors who play the central role in the construction process are typically involved with more than a single project at a time and are tied to multiple risks and deadlines. This makes them more willing to rely on their traditional practices for project delivery and resistant to invest in new methods unless there are strong incentives for them. Practically, many of the benefits of green and lean approaches are not related to what contractors are motivated to work for. Insufficient willingness and commitment to integrating the two methods is a significant obstacle to this integration.

3.2.4. Challenges to Establish a High level of Teamwork

Lean construction utilizes a variety of management techniques that are based on maximizing collaboration, facilitating communication, and enhancing the integration among the project team. The nature of construction projects in which the team combination is almost unique, as being in an environment where all the involved parties try to shift the risks to other parties makes it a challenge to establish a high level of integration. The combination of green and lean construction is expected to intensify this challenge as it extends the goals of the team, the expected standards or guidelines to follow, and the required coordination between team members to establish an efficient organizational culture that is based on pursuing the common goal collaboratively.

4. Survey Results

Industry professionals who are familiar with green and lean concepts in construction were interviewed. The survey was conducted in 28 days. The electronic version of the survey was distributed by sending the links via email to potential respondents nationwide. Additionally, several paper surveys were distributed during two construction job fairs. The respondents were construction industry professionals who were primarily involved with residential and commercial construction projects. The first question of the survey was to make sure that the respondent is familiar with the concepts of sustainable and lean construction. The responses of individuals with no background in either of the two mentioned methods were considered outliers and excluded from the data analysis.

Almost 29% of the respondents were familiar with lean and 87% were familiar with sustainable construction. In response to the level of familiarity, only 15% of them had been directly involved in a lean construction project and the rest (out of the 29%) had just heard about it. The findings also indicated that the familiarity of professionals with sustainable construction is significantly higher than lean construction. Of the 89% of respondents who knew what sustainable construction is, almost 47% of them had been involved in such projects. This can be an indication of the limited application of lean methods, particularly in residential, and commercial projects, and the high potential for increasing their application by integrating them with sustainable construction policies.

They were asked to rank the items in each category to clarify the more critical opportunities and challenges of the integration. Each respondent was asked to evaluate the significance of opportunity or challenge by selecting a number between one to five, where one shows the least significant and five represents the most significant. The relative importance index (RII) method was utilized to analyze the responses. RII is a method that aids in finding the contribution a particular variable makes to the prediction of a criterion variable both by itself and in combination with other predictor variables [68]. Equation (1) was used for the statistical analysis. Figures 2 and 3 show the results.

$$RII = \frac{\sum W}{A \times N} \quad (0 \leq RII \leq 1) \quad (1)$$

where W is the weight given to each factor by respondents and ranges between 1 and 5; A is the highest weight (i.e., 5 in this case); and N is the total number of respondents.

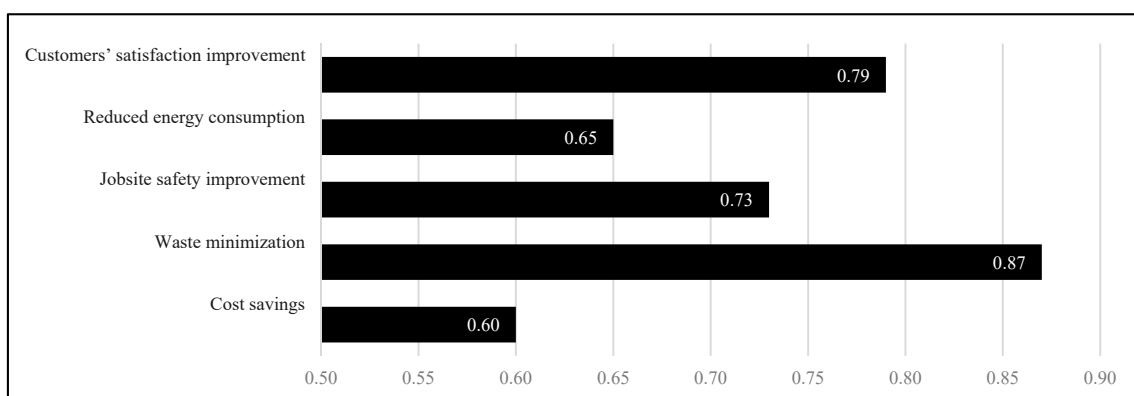


Figure 2. Relative importance index for ranking the potential opportunities for integrating green and lean approaches.

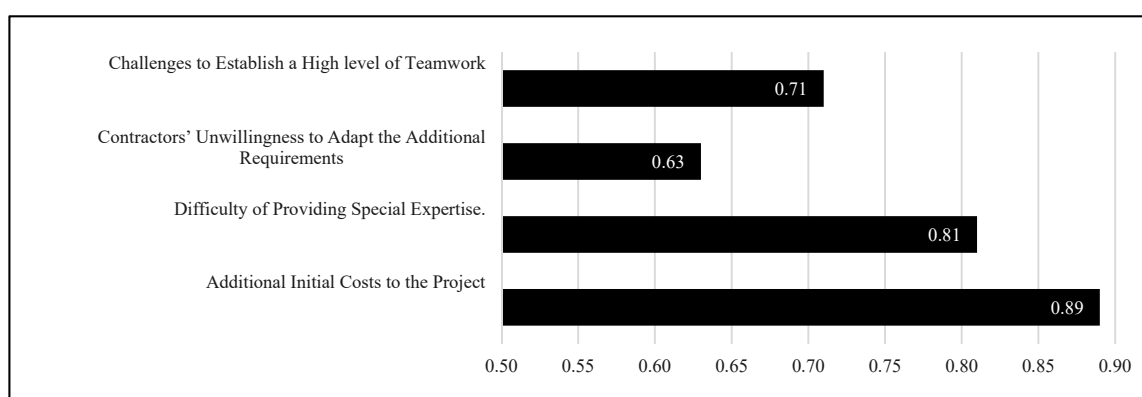


Figure 3. Relative importance index for ranking the potential challenges of integrating green and lean approaches.

5. Summary and Discussion

This research studied the implied connections between green and lean approaches in the construction industry by comparing their focuses and drivers. It was mentioned that the synergies between green and lean had been identified and supported in the literature. Additionally, evidence in the literature shows significant contributions to sustainability bottom-lines. Based on a comprehensive literature review, the opportunities for integrating the two approaches were categorized into five groups. Similarly, the challenges were listed and discussed in four groups. Industry professionals were interviewed to rank the items of each of the two groups of opportunities and challenges. The results identified waste minimization as the most significant opportunity to integrate green and lean. It was also found that the most significant challenge for this integration is the higher initial costs of the project. The study also revealed that it is more practical to consider the integration between lean and green not as a way of blending the two approaches and forming a third approach, but as a tool to take advantage of the linkages between the two concepts and maximize their synergetic contribution to one-another. Future studies should focus on a practical approach to develop a framework for this integration by considering the possible limitations and taking advantage of the existing opportunities that were explained in this paper.

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