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# EXPLORING THE ROLE OF LEAN CONSTRUCTION IN DECARBONIZING THE BUILDING INDUSTRY: INSIGHTS FROM INDUSTRY EXPERTS

**Alberto E. Pozzer[1], Christopher Rausch[2], and Fernanda Leite[3]**

## ABSTRACT

The building and construction industry continues to be one of the major contributors to carbon emissions, representing 37% of the global share. Across the approaches being used to decarbonize this sector, the reduction of waste is a shared aim with lean construction. While previous studies have reviewed the associated factors of lean to decarbonization, the actual impact and applicability in real-world practice still require feedback from industry practitioners. This paper aims to address that gap with a mixed-methods approach that includes a literature review to identify lean enablers of decarbonization, and input from industry members to evaluate their effectiveness. According to the assessment, the main factors are the optimization of design, the enhancement of processes on-site and off-site, the improvement of transportation, and avoiding rework. Waste reduction is already included in these factors since they reduce different types of waste, including materials, time, and energy. The industry practitioners qualified optimization of design as the most impactful factor, while optimization of transportation was the least impactful and showed significant variance across responses. The participants highlighted that lean construction contributes to reducing carbon emissions while also decreasing the project cost and duration, which is a significant difference from other decarbonization strategies.

## KEYWORDS

Lean construction, decarbonization, carbon emissions, industry experts.

## INTRODUCTION

In order to limit climate change and global warming, all industry sectors are required to reduce their greenhouse gas (GHG) emissions in the short term (Intergovernmental Panel on Climate Change IPCC, 2022). In particular, the building and construction sector is one of the major contributors to global greenhouse gas emissions, representing 37% of the total share (UN Environment Programme, 2023). A significant part of these emissions comes from the use of materials, waste generation, as well as construction and transportation processes (Ibn-Mohammed et al., 2013). Taking into account the upstream and downstream supply chain, the

1 Ph.D. Student, Fariborz Maseeh Department of Civil, Architectural and Environmental Engineering, The University of Texas at Austin, USA, emmanuelpozzer@utexas.edu, orcid.org/0009-0001-6755-0176

2 Assistant Professor, Fariborz Maseeh Department of Civil, Architectural and Environmental Engineering, The University of Texas at Austin., USA, c.rausch@utexas.edu, orcid.org/0000-0002-8927-2285

3 Professor, Fariborz Maseeh Department of Civil, Architectural and Environmental Engineering, The University of Texas at Austin., USA, fernanda.leite@utexas.edu, orcid.org/0000-0002-7789-4474

construction sector accounts for 50% of the total raw material demand and creates waste at a rate that doubles the municipal solid waste (Norouzi et al., 2021; US Environmental Protection Agency, 2020). It is projected that under the business-as-usual scenario, carbon emissions associated with materials and construction activities will comprise half the emissions in the building sector by 2050 (UN Environment Programme, 2023). This type of emission can be reduced by implementing better project designs, employing more effective use of materials, reducing waste, and applying more efficient construction processes, among others (Pomponi & Moncaster, 2016). Since lean construction (LC) presents the shared aim of reducing the waste of materials and energy during the design, construction, and operation of buildings; LC can be seen as a method to reduce carbon emissions in the construction sector (Sarhan & Pretlove, 2021).

Lean Construction refers to the application of lean production concepts in the context of construction projects (Koskela, 2020). This technique results from extending the classical theory of production to the theories of flow and value generation (Koskela, 2000). In practical changes, this includes restructuring projects to achieve specific goals, applying controls during execution, and achieving improvement during and between projects (Koskela, 2000). The ultimate goal is to minimize wasteful time, materials, costs, and other resources while maximizing their value (Koskela et al., 2002; Li et al., 2024).

Given the potential of LC to improve efficiency and minimize waste, previous studies have explored the potential of lean construction to achieve carbon reductions (Sarhan & Pretlove, 2021). According to information available in the academic literature, the construction industry can improve several sustainability aspects through the application of lean principles (Babalola et al., 2019). However, to evaluate the actual impact of lean on industry practices, it is important to combine the latest academic insight with input from industry experts. This study aims to assess recent literature and obtain an opinion-based evaluation from industry practitioners to evaluate the contributing factors of lean construction to reduce carbon emissions.

# BACKGROUND

The relationship between lean construction and sustainability has been studied for several years. At the 1998 Annual Conference of the International Group for Lean Construction, Huovila and Koskela evaluated the impact of Lean Construction principles on sustainable development (Huovila & Koskela, 1998). Since then, several studies have been conducted on this topic, and there have been bibliometric reviews that summarized their main findings (Babalola et al., 2019; Carneiro et al., 2012; Sarhan et al., 2018). According to the compilatory work, lean and sustainable construction are compatible and share common objectives such as reducing waste, improving the efficiency of activities, improving design, and minimizing errors (Babalola et al., 2019; Carneiro et al., 2012). However, significant limitations, unexplored work, areas of improvement, and opportunities for further work were reported as well (Sarhan et al., 2018). Although the previous bibliometric research sets a preliminary basis for this analysis, more recent information is needed because these areas of study are constantly evolving.

Regarding industry insights on the relationship between LC and sustainability, previous studies have collected opinions from industry practitioners. For instance, Maris and Parrish conducted interviews to evaluate the confluence of green and lean construction, finding that a synergy exists between the two concepts (Maris & Parrish, 2016). Other authors employed case studies and identified that when implementing lean and sustainable principles simultaneously, the benefits of these approaches can be achieved more efficiently (Campos et al., 2012; Parrish, 2012; Vieira & Cachadinha, 2012). Although these findings are valuable to the body of knowledge, more recent data should be collected from industry practitioners. In addition, it is important to identify not only if the two paradigms complement each other, but also to evaluate which aspects or lean have a higher impact and applicability on decarbonization.

# METHODOLOGY

The research procedure is presented in Figure 1. The study employs a mixed-methods approach based on a systematic literature review and a structured questionnaire for industry experts. The literature review is performed to identify the factors for which LC can contribute to the reduction of carbon emissions. The questionnaire is employed to obtain the insight of experts and to quantify the impact of these factors on carbon reduction. In addition, it serves as a source to identify other factors that can positively or negatively affect decarbonization.

The systematic literature review consists of three core steps which are represented in Table 1. First, a set of keywords is developed to perform the search for academic articles in the Scopus and International Group for Lean Construction (IGLC) databases. Since this research aims to evaluate recent literature, only articles from 2020 to 2024 are included. For the Scopus database, the articles are filtered to include only construction-related journals. The second steps consist of analysing the titles and abstracts of the studies retrieved to filter those relevant to the objectives of this research. The criteria for filtering and reviewing the articles are summarized in Table 1. Finally, the remaining articles are assessed in detail to extract and categorize the contributing factors of lean construction to decarbonization. The resulting categories constitute the classification employed to develop the questionnaire for the following stage of the study.

The structured questionnaire was conducted with experts in the construction sector. The sample was obtained from a previous study that assessed the current landscape of the industry in decarbonizing capital projects. The subjects possess extensive professional experience, are based in diverse regions, and represent different types of stakeholders (project owners, contractors, etc.). Participants were invited by email to participate in the current study by responding to a questionnaire. Participants were each asked the same questions about the effectiveness of lean construction in reducing carbon emissions based on factors identified in the literature review and qualify these effects as none, low, medium, and high. Experts were also asked to indicate if any of these factors negatively impact decarbonization or present a trade-off. Finally, respondents were asked to mention factors not included in the original list, as well as characteristics of lean construction that could increase carbon emissions, or produce additional benefits along with the carbon reductions. These inputs are summarized as complementary information to that identified in the literature review.

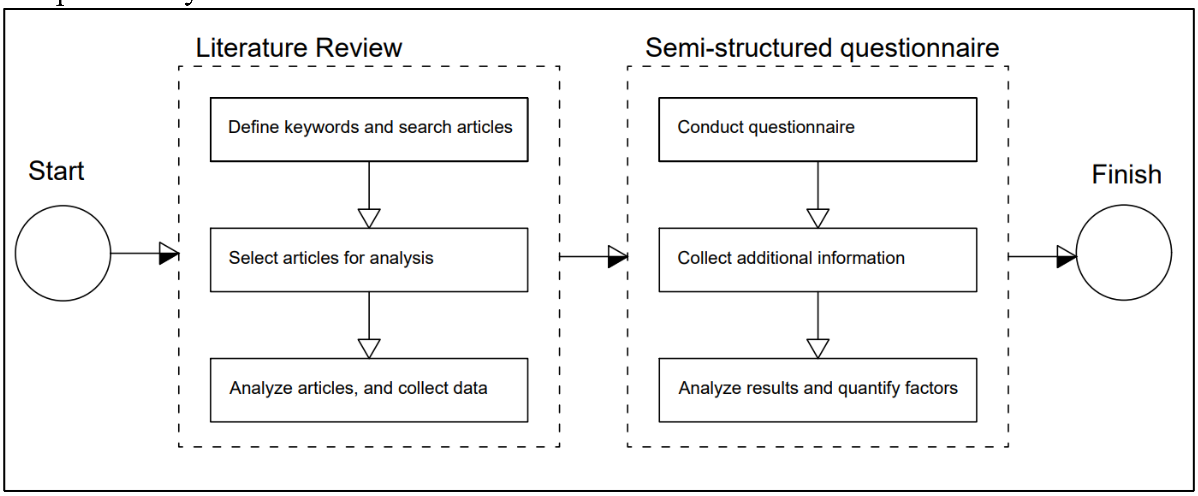


Figure 1: Research Methodology

Table 1: Literature review approach

| **1) Search articles** | **2) Review the title and abstract** | **3) Full Article Review** |
|---|---|---|
| Keywords and filters | Criteria | Criteria |
| Keywords<br>Lean Construction<br>Carbon<br>Green<br>Decarbonization<br>Sustainability<br><br>Filters (only for Scopus)<br>Years: 2020-2024 (filter not available in IGLC)<br>Engineering<br>Journal of Building Engineering<br>Construction and Building Materials<br>Energy and Buildings<br>Automation in Construction | Removed repeated articles<br>Remove articles older than 2020-2024 (for IGLC)<br>The paper analyses the relationship between lean and carbon emissions<br>The paper demonstrates existing relationships (not future visions or proposed new technology)<br>The scope of the paper is within the construction sector<br>The scope of the paper focuses on the delivery of the projects (not operation)<br>The scope of the paper is in the execution of the project (not in other parts of the supply chain) | Remove any additional article not aligned with the scope criteria defined in step 2)<br>Extract the contributing factors of lean construction to decarbonization<br>Group the factors that are similar into comprehensive categories |

# RESULTS AND DISCUSSION

## LITERATURE REVIEW

The literature review was conducted following the approach illustrated in Table 1. As indicated in Figure 2, the process performed retrieved 258 articles in the initial search, 25 remained after the first screening, and 11 conformed to the final set after the detailed review. The main results are summarized in Table 2 in which the factors of lean construction contributing to decarbonization are grouped into categories. The classification resulted in six divisions: the reduction of waste, the optimization of design, the optimization of the construction process on-site and off-site, the optimization of transportation, and avoiding rework. The elements included in these categories and the corresponding references are also included in Table 2. Each of these factors was included in the questionnaire for which the industry experts had to qualify their contribution and effectiveness in reducing carbon emissions. It is worth noting that not all of these factors necessarily have a positive impact; moreover, some of them can potentially have a negative impact. For instance, the implementation of offsite production may reduce carbon emissions by improving the efficiency in the preassembly however it may also increase the emissions due to the transportation needs (Paneru et al., 2024). Another important clarification is that the reduction of waste is a cross-cutting characteristic that is inherently included in the other factors. For that reason, it was not included in the questionnaire independently but it was clarified to the participants that each factor includes the consequent reduction of waste.

### Questionnaire

Respondents to the questionnaire (eight in total) have deep experience in the construction industry as shown in Figure 3. Each respondent qualified the impact of key factors to reduce carbon emissions of projects and the total count of these answers are summarized in Figure 4 and Table 3.

The total count of answers was selected as the parameter to represent the results due to the small size of the sample. The most impactful category was optimization in design which was qualified as high for four subjects and medium for two. In the second place, is the optimization of off-site processes which has the same values for high and medium, but also one subject categorized it as low. The least impactful category was optimization of transportation which obtained three counts for high, two for medium, one for low, and one for none.

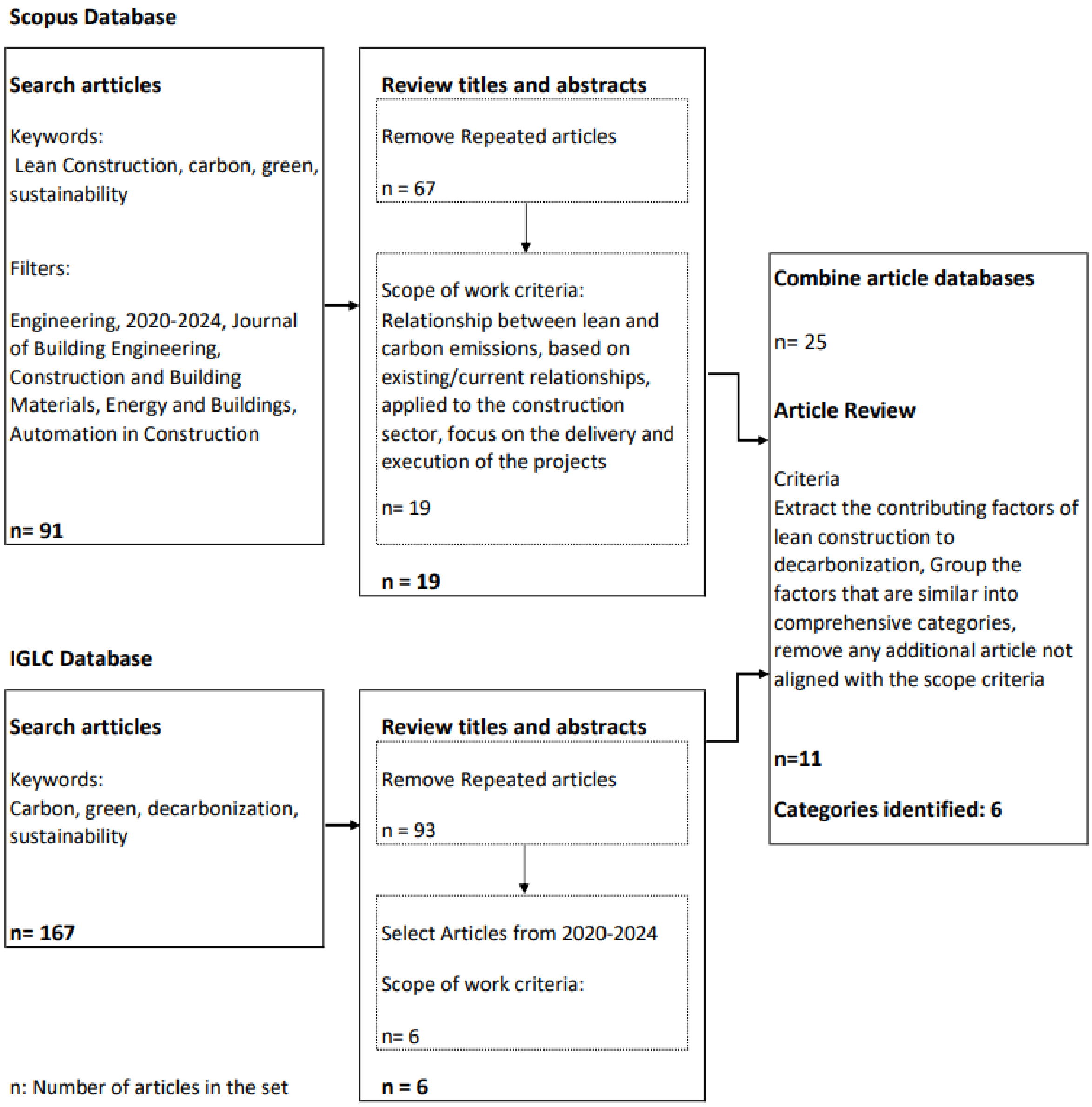


Figure 2: Summary of the literature review process

Table 2: Factors by which lean construction contributes to reducing the carbon emission of projects according to the literature review.

| Factor | Description | References |
|---|---|---|
| Reduce waste | Related to all the factors below:<br>Avoid waste of materials, time, and cost during construction<br>Avoid waste and additional materials and time for rework and defects<br>Avoid energy waste due to inefficiency in processes | (Assaf et al., 2024; Berroir et al., 2021a; Caldarelli et al., 2022; Dhawan et al., 2024; Hussain et al., 2024; Li et al., 2024; Onyenokporo et al., 2024; Raza & Zhong, 2024; Sarhan & Pretlove, 2021; Tabrizikahou & Nowotarski, 2021; Wibowo et al., 2020) |
| Optimization of design, and avoiding design errors | Efficient design of components<br>Minimize design errors | (Assaf et al., 2024; Hussain et al., 2024; Tabrizikahou & Nowotarski, 2021; Wibowo et al., 2020) |
| Optimization of construction processes on-site | Improve efficiency construction process<br>Eliminate superfluous processes<br>Reduce emissions from waiting equipment<br>Avoid obsolete and non-automated machinery | (Berroir et al., 2021b; Caldarelli et al., 2022; Hussain et al., 2024; Raza & Zhong, 2024; Sarhan & Pretlove, 2021; Tabrizikahou & Nowotarski, 2021) |
| Optimization of processes off-site | Avoid overproduction of materials<br>Reduce or extra-processing of components<br>Improve efficiency by preassembling off-site | (Li et al., 2024; Onyenokporo et al., 2024; Raza & Zhong, 2024) |
| Optimization of transportation | Reduce transportation distances<br>Eliminate unnecessary transportation<br>Use of efficient transportation methods | (Dhawan et al., 2024; Li et al., 2024; Raza & Zhong, 2024) |
| Avoid rework | Construction according to design and specifications<br>Avoid defects and damage | (Raza & Zhong, 2024; Wibowo et al., 2020) |

Table 4 updates the information presented in Table 2 by incorporating additional information provided by the participants. This includes additional factors with positive and negative effects on decarbonization. The reduction of the total project timeline was mentioned as a factor by which lean construction contributes to reducing carbon because it reduces fixed daily energy consumption. Other factors mentioned were the reduction of constraints during project execution and the enhancement in fuel consumption; however, these factors are already considered in the optimization of activities on-site. Several respondents also highlighted how the reduction of waste is a transversal factor to all the other categories. As a negative factor, it was pointed out that just-in-time delivery may not be as carbon efficient as producing, moving, and handling items in bulk, and therefore could have a trade-off between the efficiency of the processes and the energy intensity. Table 4 also includes a count of the factors based on the results in Figure 4.

One additional insight from the experts was the relevance of lean construction as a method to simultaneously improve different project metrics. Although this study focuses on decarbonization, respondents highlighted that LC improves several performance indicators. For example, the total project duration and the cost can be reduced in comparison to a traditional project execution. This is a major difference from other decarbonization strategies that generally present a trade-off between carbon emissions and other project metrics, especially cost.

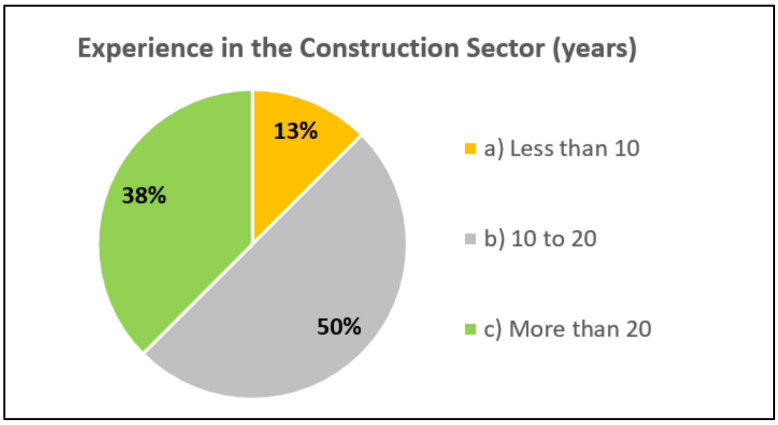


Figure 3: Construction sector experience of questionnaire respondents

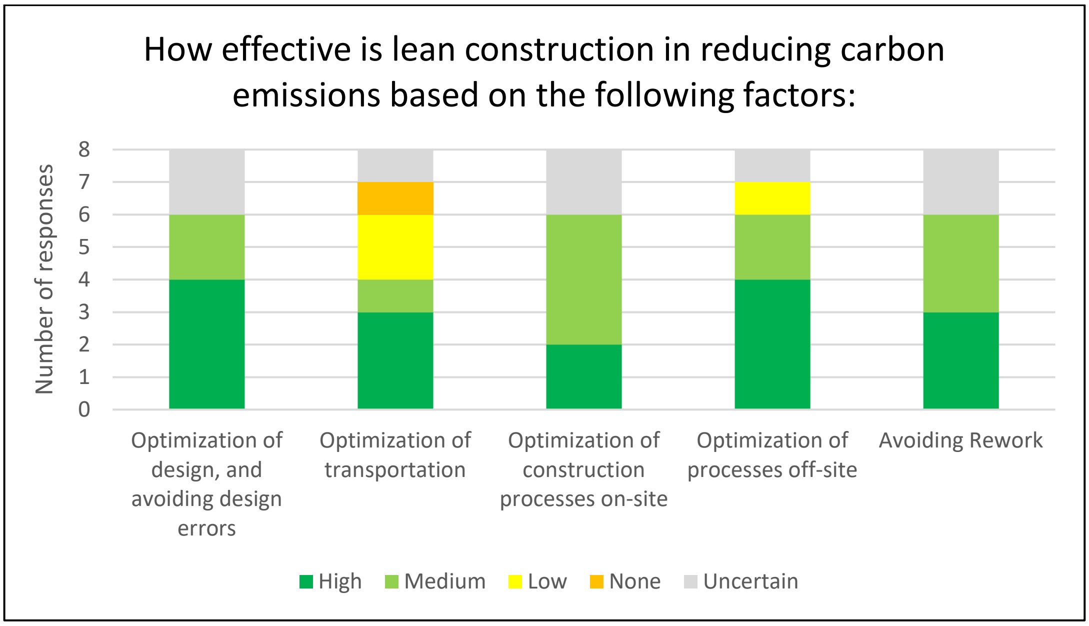


Figure 4: Effectiveness of lean construction factors for decarbonizing construction projects

Table 3: Count of questionnaire responses

| Factors | High | Medium | Low | None | Uncertain |
|---|---|---|---|---|---|
| Optimizing the design | 4 | 2 | 0 | 0 | 2 |
| Optimizing transportation | 3 | 1 | 2 | 1 | 1 |
| Optimizing on-site processes | 2 | 4 | 0 | 0 | 2 |
| Optimizing off-site processes | 4 | 2 | 1 | 0 | 1 |
| Avoiding rework | 3 | 3 | 0 | 0 | 2 |

Table 4: Updated factors by which lean construction contributes to reducing the carbon emission of projects according to the literature review and structured questionnaire.

| Factors | Effectiveness of lean construction to reduce carbon emissions | Variability in responses |
|---|---|---|
| Optimizing the design | High | Low variability |
| Optimizing transportation | Medium-low | High variability |
| Optimizing on-site processes | Medium | Low variability |
| Optimizing off-site processes | High | Intermediate variability |
| Avoiding rework | High-medium | Low variability |
| Reduction of project duration | Not measured | Not measured |
| Carbon intense process | Negative | |

# LIMITATION

The questionnaire was sent to 20 industry professionals and completed by eight, which constitutes a small sample size. A larger sample would provide a better representation of the population and permit the use of other statistical parameters to represent the results than just the count of responses. Furthermore, the possible existence of a sample bias must be acknowledged. Participating in the questionnaire was voluntary and the professionals who responded may have a particular interest in sustainability and/or lean construction, which may not represent the perspective of all the practitioners of the construction industry.

# CONCLUSIONS

This study analysed the contributing factors of lean construction to reduce carbon emissions in the construction of buildings. The research approach utilized a literature review to identify the contributing factors and a structured questionnaire to qualify their effect on decarbonization. The factors identified were the optimization of design, the optimization of the construction process on-site and off-site, the optimization of transportation, and avoiding rework. The reduction of waste was not included as a separate factor since it is a common characteristic of all the factors previously mentioned and therefore it is considered a general category already included in all the others. Additionally, the reduction of the project timeline was identified by the experts as another contributing factor. The respondents also highlighted that these benefits come without additional cost and time, or even with a reduction of them because of the application of lean practices. On the other hand, the high carbon intensity of some lean techniques or processes was mentioned as a possible negative factor.

Insights from industry experts were employed to classify the contribution of these factors qualitatively It is worth noting that despite some dispersion in the responses, all of the factors were categorized as having at least a moderate positive effect in reducing carbon emissions. The most relevant factor was the optimization of design which was qualified for four respondents as having a high impact and for two respondents as moderate. On the other hand, the least positive factor was transportation which presented a high variability in responses ranging from high impact to none. The other three factors had intermediate scores ranging from moderate to high. These effects are combined with other benefits of lean principles such as the reduction of project timeline and cost, make lean construction a key strategy to implement when trying to reduce carbon.

Insights provided by industry experts can help researchers better understand the relationships between lean construction and decarbonization. The analysis shows that LC includes at least five aspects that produce a moderate to high impact on reducing carbon emissions. Since the best-qualified aspect was the improvement in design efficiency, the results draw attention to the importance of planning upfront and implementing decisions in the early phases of the projects. This correlates with previous project management studies that established the correlation between decision-making and the project phase (World Business Council for Sustainable Development, 2021). The earlier the implementation of decisions, the higher the carbon reduction potential. For this reason, the timely and proactive use of lean construction can serve as a key strategy to optimize the design and construction processes, ultimately contributing to carbon reductions in building projects.

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