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LEAN THINKING FOR GREEN BUILDING: BARRIERS FOR LEAN INTEGRATED SUSTAINABLE CONSTRUCTION

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ABSTRACT

Green building has become a central focus in modern construction discourse, representing a practical and measurable approach to achieving sustainable construction in response to the thriving need for the construction industry to adopt sustainable construction practices, particularly in response to the persistent challenges that characterise the sector, such as excessive material waste, high energy consumption, environmental degradation, inefficient resource utilisation, and the generation of significant carbon emissions. Despite the well-known benefits of sustainable construction, most countries are still widely familiar with the traditional construction, due to the bottlenecks that hindered the widespread adoption of sustainable construction. Subsequently, lean thinking has been identified as a foremost solution for the effective implementation of sustainable construction, owing to the close conceptual alignment between the two approaches, as well as the extensive benefits offered by lean principles in reducing waste, enhancing efficiency, and promoting value-driven processes. However, the implementation of lean integrated sustainable construction is obstructed by numerous barriers. Therefore, this study aims to investigate the barriers to lean integrated sustainable construction. The study employed a quantitative research approach using a questionnaire survey, through which a total of 120 responses were gathered via snowball sampling. Findings revealed a total of 32 highly significant barriers to lean integrated sustainable construction, from a total of 94 barriers identified through the literature review and data collection. Out of these, the most significant barriers include employees' resistance to lean, resistance to change, lack of incentives and motivation, shortage of manpower, and an unfriendly organisational culture, which collectively highlight a deep-rooted human-centricity in lean thinking. The study provides empirical insights for practitioners, including the identification of relevant barriers and the highlighting of their significance, enabling enhanced practices and informed decision-making, thereby contributing to address a gap in the literature.

Keywords: *Barriers; Green Buildings; Lean Construction; Sustainable Construction.*

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1. INTRODUCTION

Construction industry has evolved through several chronological stages, starting with ancient shelters constructed from stone to the multifaceted international construction projects (Ngowi et al., 2004). Despite its dominant role in economic growth and social improvement, the construction industry has significant unfavourable impacts, with the buildings and construction sector responsible for 21% of global greenhouse gas emissions, and 37% of energy and process-related CO_2 emissions in 2022 (United Nations Environment Programme, 2024), and numerous indirect environmental consequences including, significant waste generation (Chandrappa & Das, 2024), noise pollution (Bouzir et al., 2024), and urban heat island effect (Iungman et al., 2024). These negative consequences highlight the thriving need for implementing a strategic approach aimed at minimising the negative impacts of the construction industry, where the concept of sustainability has emerged through the construction industry.

Sustainable construction has rapidly been implemented in recent years due to its remarkable potential to address numerous issues in the construction industry, with a central focus on the proper distribution of global resources (Cuesta et al., 2022), waste minimisation (Djokoto et al., 2014), optimum resource utilisation (Lima et al., 2021), and reuse and recycling practices (Pearce, 2006). Nevertheless, sustainable construction remains a challenging task, hindered by numerous obstacles, and requires an effective approach for successful implementation (Singh, 2016). Importantly, lean construction can serve as a holistic approach to enhance the successful realisation of sustainable construction, being a philosophy based on the underlying principles of waste minimisation, value maximisation, and continuous improvement (Akanbi et al., 2019). However, lean integrated sustainable construction faces significant implementation challenges (Marhani et al., 2012), necessitating a strong need to properly identify these barriers within the construction industry. Therefore, concerns arise regarding the barriers to the integration of sustainable construction and lean construction. Moreover, the lack of research investigating the barriers to lean integrated sustainable construction has contributed to limited lean implementation within the construction sector (Madhushani et al., 2024). Consequently, there is a clear need to investigate the significance of the barriers to lean integrated sustainable construction, in order to enhance the implementation of lean construction and thereby drive sustainable construction. This research is therefore aimed at investigating the barriers to lean integrated sustainable construction. Achieving this aim will bridge the theoretical gap and provide insights for practitioners to effectively implement both lean construction and sustainable construction, ultimately contributing to the sustainability of the global construction sector. The paper starts with an introduction to the topic and research gap followed by a comprehensive literature review on sustainable construction and lean construction. The methodology section outlines the research process, and the findings are presented with a discussion. Subsequently, research implications are provided followed by future research areas.

2. LITERATURE REVIEW

2.1 NEED OF SUSTAINABLE CONSTRUCTION

Initially, Kibert (1994) proposed the first definition of sustainable construction as "the creation and responsible management of a healthy built environment based on resource efficient and ecological principles." Notably, Baloi (2003) emphasised that there is a worldwide concern regarding the alignment of the construction industry with sustainable construction due to the significant negative impacts of construction activities. Importantly, financial issues such as insufficient financial resources, and late payments (Abdul-Rahman et al., 2014), disrupt the efficient operations of projects while the issues such as unforeseen site conditions (Amarasekara et al., 2018), poor site management (Alaghbari et al., 2007) cause project delays. Moreover, as many studies have identified, stakeholder-related human problems (Thapanont et al., 2018), quality problems (Zou et al., 2007), health and safety problems (Kadiri et al., 2014) and environmental problems (Gangolells et al., 2009) contribute to inefficiencies including time and cost overruns, and low-quality outcomes, which hinder the industry's long-term sustainability.

As a solution, several studies highlight the driving factors of sustainable construction in a more comprehensive manner, where the environmental drivers include greater energy efficiency (Darko et al., 2017), improved indoor environmental quality (Darko & Chan, 2017), and land-use regulations, while the economic drivers are identified as the value for money in project delivery (Whang & Kim, 2015), and support for the local economy (Pearce, 2006), and the social drivers of sustainable construction are identified as service quality (Abidin, 2010), and security (Whang & Kim, 2015). Ultimately, all these aspects collectively emphasise the urgency of widespread adoption of sustainable construction practices to achieve a more sustainable built environment.

2.2 CHALLENGES IN IMPLEMENTING SUSTAINABLE CONSTRUCTION

Despite the well-known benefits of sustainable construction practices, most countries are still widely familiar with the traditional construction industry, due to the bottlenecks that hindered the widespread adoption of sustainable construction practices (Davies & Davies, 2017). Consequently, financial issues such as higher initial costs and long payback periods (Ahn et al., 2013) discourage many contractors, especially in regions with weaker economies. Political factors such as limited government promotion (Aghimien et al., 2018), and weak regulations (Mosly, 2015) further hinder the implementation of sustainable construction. Additionally, managerial barriers, including a lack of coordination and communication between stakeholders significantly restrict the adherence to sustainable construction (Serpell et al., 2013). Moreover, knowledge gaps, including a lack of training and understanding of sustainability concepts (Abraham & Gundimeda, 2018) create significant obstacles to widespread adoption of sustainable construction, which is compounded by social-cultural barriers where cultural change resistance (Enshassi & Mayer, 2005) and the tendency to maintain current practices further disrupt the smooth transition to sustainable construction. Similarly, technical barriers, including shortages of skilled labour and inadequate sustainability measurement tools (Häkkinen & Belloni, 2011), along with physical constraints such as scarcity of green materials, equipment, and technologies (Darko & Chan, 2017), create substantial restrictions to the effective implementation of sustainable construction. Collectively, these barriers hinder the adoption of sustainable construction worldwide. Therefore, there is a growing need to explore better ways to ensure the successful adoption of sustainable construction. Consequently, lean construction can be considered a foremost solution for effective implementation of sustainable construction within the construction industry.

2.3 NEED OF LEAN CONSTRUCTION FOR SUSTAINABLE CONSTRUCTION

The origin of lean philosophy is related to the industrial process, where this innovation business approach has changed the paradigm and management concepts of the 20th century (Kelendar, 2020). With the rapid advancement of technologies, many industries experience a growing prominence of the application of lean production principles in various sectors (Akanbi et al., 2019). Koskela (1993) introduced the first reference to apply lean principles in the construction industry as a solution to chronic issues of industry such as insufficient quality, low productivity, inadequate safety, and poor working conditions. Delving further into this notion, Marhani et al. (2012) defined lean construction as "the concurrent and continuous improvement of the construction project by reducing waste of resources and, at the same time, increasing productivity and securing a better health and safety environment to fulfil the client's requirements, as well as contributing towards a sustainable and greener environment". With the widespread adoption of lean construction, many researchers emphasised that lean construction serves as a holistic approach to solve most issues in the construction industry. Accordingly, the major economic benefits of lean construction include reduced rework, improved quality, (Besklubova & Zhang, 2019), value achievement (Opoku et al., 2024), project and labour cost reduction (Parfenova et al., 2020), whereas the social benefits of lean construction include enhanced teamwork and transparency, collaborative communication among stakeholders, reduced conflicts and disputes (Jagannathan et al., 2024), while the environmental benefits of lean construction include more controllable material storage, improved safety measures, enhanced quality of environment, reduced pollution and emissions (Pejić et al., 2023), water conservation , energy consumption savings (Shaqour, 2022). Collectively, these lean construction benefits demonstrate their extensive potential to achieve the sustainable construction, simultaneously emphasising the importance of lean integrated sustainable construction implementation for the advanced achievement of construction goals.

2.4 BARRIERS FOR LEAN INTEGRATED SUSTAINABLE CONSTRUCTION

Albalkhy and Sweis (2021) emphasised that despite the evident benefits of lean construction, numerous hindrances arise when amalgamating the lean principles into construction projects. Moreover, various studies have identified the barriers to implement lean integrated sustainable construction, focusing on different categories. Accordingly, Demirkesen et al. (2019) classified them as political barriers, economic barriers, workforce barriers, cultural barriers, managerial barriers, communication barriers, and technical barriers. In contrast, Alinaitwe (2009) analysed the barriers to implement lean construction by dividing them into three different aspects: management, organisation, and design-related factors. On the other hand, Moradi and Sormunen (2023) stated, "People are the main root cause of the barriers, enablers, and implications of lean construction adoption and implementation." Similarly, numerous studies highlighted that people are the most crucial factor in enabling lean practices, where social barriers including workforce, cultural, managerial, communication, and educational challenges collectively identified as the major obstacles to sustaining a long-term lean implementation (Sarhan & Andrew, 2012; Shang & Pheng, 2014). Therefore, there is a need to thoroughly investigate the barriers to lean integrated sustainable construction, to secure a better future for the construction industry.

2.5 NEED OF THE RESEARCH

Focusing on existing literature clearly indicates that the critical issue faced by many construction firms is the absence of proper prioritisation of the barriers to lean integrated sustainable construction (Madhushani et al., 2024). Moreover, there is a notable lack of research aimed at identifying the potential to minimise the barriers to green buildings through lean implementation. Most existing studies tend to address lean construction and sustainable construction separately, failing to provide a comprehensive understanding of the combined implementation challenges. This lack of clarity poses a significant gap for both researchers and industry practitioners, making it difficult to develop targeted strategies. Therefore, this research aims to fill this gap by investigating the key barriers to lean integrated sustainable construction, contributing both to academic knowledge and practical improvements in the construction sector.

3. METHODOLOGY

A comprehensive literature review was initially conducted by referring to journal articles, books, theses and dissertations, reports, web pages, other online sources, and conference papers to identify the barriers to lean integrated sustainable construction. Accordingly, a total of 80 barriers were identified under nine categories, as presented in Table 1. Subsequently, data collection for the study was conducted using a questionnaire survey to identify the most significant barriers to lean integrated sustainable construction. According to Östlund et al. (2011), quantitative research is effective for identifying patterns, testing hypotheses, and ranking factors based on empirical data, which is critical for understanding widespread industry challenges. In answering this research question, the authors adopted a quantitative method by conducting a questionnaire survey, utilising

Figure 1: Profile of the sample

snowball sampling as the sampling technique. The survey was distributed via Google® Forms to 150 industry professionals working in the construction industry who are knowledgeable about lean integrated sustainable construction, resulting in the collection of approximately 120 responses. The questionnaire consisted of 24 questions aimed at gathering data on the significance level of barriers to implementing lean integrated sustainable construction in the construction industry. The primary objective of this survey was to identify and prioritise the most significant barriers to implementing lean integrated sustainable construction. Moreover, Figure 1 illustrates the professional backgrounds of the respondents along with their educational and professional qualifications.

Accordingly, the innermost layer represents the professional designations of the respondents, the middle layer represents their educational qualifications, and the outermost layer indicates their professional qualifications. The composition of the sample reflects a diverse group of construction-related professionals with high levels of expertise, enhancing the overall proficiency of the sample and the reliability of the responses gathered.

Quantitative data need to be analysed using mathematical techniques together with statistical concepts (Weyant, 2022). Therefore, quantitative data gathered from the questionnaire survey analysed using Weighted Mean Rating (WMR) method and Standard Deviation (SD). The mean, which is also known as the average, is the most frequently used measure of central tendency for numerical variables (Manikandan, 2011). It provides a comprehensive representation of the data set by analysing every value within it, thereby offering valuable information and reliable interpretations (Sial & Abid, 2023). Mean score of a particular item is derived as,

$$Mean = \frac{\sum_{i=1}^{5}(x_i \times f_i)}{n} \qquad Equation\ (1)$$

where, fi = frequency of responses and n = number of responses.

Moreover, standard deviation can be identified as a statistical measure for quantifying the dispersion or spread of data in relation to its mean (Przystupa et al., 2022). Thus, it was used in this study to determine the spread of findings on the participants' knowledge and opinions regarding the significance of the barriers. Accordingly, the following formula was used for that standard deviation.

$$Standard\ Deviation = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}} \qquad Equation\ (2)$$

Where: x_i = Weightage given to each variable based on the level of agreement; $\bar{x}$ = Mean of the data set; n = Number of respondents.

Furthermore, Cronbach's alpha calculation is generally used as a measure of internal consistency and reliability (Tavakol & Dennick, 2011). Accordingly, Cronbach's alpha was used to measure the consistency of the Likert scale data obtained through the questionnaire survey.

$$Cronbach's\ Alpha\ (\alpha) = \frac{k}{k-1}\left(1 - \frac{\sum V_i}{V_t}\right) \qquad Equation\ (3)$$

Where α = Cronbach's alpha coefficient; k =Number of items in the scale; $\sum V_i$ = Sum of the variances of each individual item; V_t= Total Variance of the total scale. In this research, IBM SPSS Statistics 26 software was used to calculate statistical measures.

4. FINDINGS AND ANALYSIS

4.1 BARRIERS OF LEAN INTEGRATED SUSTAINABLE CONSTRUCTION

Through an extensive literature review, a total of 80 barriers to lean integrated sustainable construction were initially identified. Additionally, a structured questionnaire survey revealed 14 new barriers reported by industry respondents, bringing the total to 94 distinct challenges. With the aim of identifying the most significant barriers, respondents were asked to rank the level of significance of each barrier using a five-point Likert scale, between "Not Significant" and "Highly Significant". Maree and Pietersen (2016) suggested that Cronbach's alpha value of 0.90 indicates high reliability, 0.80 indicates moderate reliability, and 0.70 indicates low reliability. Accordingly, a reliability test was conducted for all the barrier variables used in this study. Consequently, the reliability test conducted on the 94 variables revealed Cronbach's alpha coefficient of 0.893, reflecting a high level of reliability, and confirming that the measurement instrument used in this study is dependable and consistent. Subsequently, the weighted mean rating method was applied to evaluate the relative rankings of each barrier, in descending order of significance, with the results summarised in Figure 2.

These barriers ranged from 'Employees' resistance to lean' (mean = 4.302; SD = 0.740) which is the highest ranked to "Incomplete complicated design" (mean = 1.471; SD = 1.155) which is the least ranked. In line with the threshold recommended by Olanrewaju et al. (2020), a mean score of 3.50 or higher was used as the benchmark to identify the most critical barriers, especially in construction related research. Accordingly, 32 of the 94 barriers surpassed this threshold and were considered highly significant in hindering the implementation of lean integrated sustainable construction practices. The results indicate that employees' resistance to lean implementation, emerged as the most critical barrier, with a WMR of 4.302. This highlights a deep-rooted behavioural and cultural challenge within construction organisations. Closely following are resistance to change and the lack of incentives and motivation, both pointing towards the critical influence of organisational culture and human resource management. The persistence of these barriers implies that the successful adoption of lean integrated sustainable construction is not only a technical or procedural challenge but a deeply human-centric one. Furthermore, barriers such as manpower shortages (WMR = 4.246), unfriendly organisational culture (WMR = 4.215), and the lack of a long-term lean philosophy (WMR = 4.191) further reinforce the argument that workforce-related and cultural factors are pivotal. It is evident that even in technologically capable environments, without strong managerial backing, continuous training, and cultural realignment, lean sustainability efforts may remain superficial or unsustainable. Moreover, barriers such as 'lack of technical capabilities/green initiatives', 'lack of top management support', and 'lack of government support for research', each with a rounded mean rating of 4.1, highlight the importance of government support, managerial commitment, and technical capability in enhancing lean implementation. This underscores the multidisciplinary and collaborative nature of a lean construction.

Conversely, the barriers fall below the WMR benchmark of 3.4 include external and project specific constraints such as market conditions, unclear project definitions, subcontracting practices, and incomplete designs. Though less critical, these issues still represent practical impediments, especially under complex or large-scale project conditions. The wide spread of standard deviations across these items suggests varying perceptions among respondents, likely influenced by contextual differences across construction environments. Overall, these findings emphasise the need for a systemic transformation that integrates behavioural change, institutional learning, and participative leadership as key pillars for driving lean culture in pursuit of sustainability in construction.

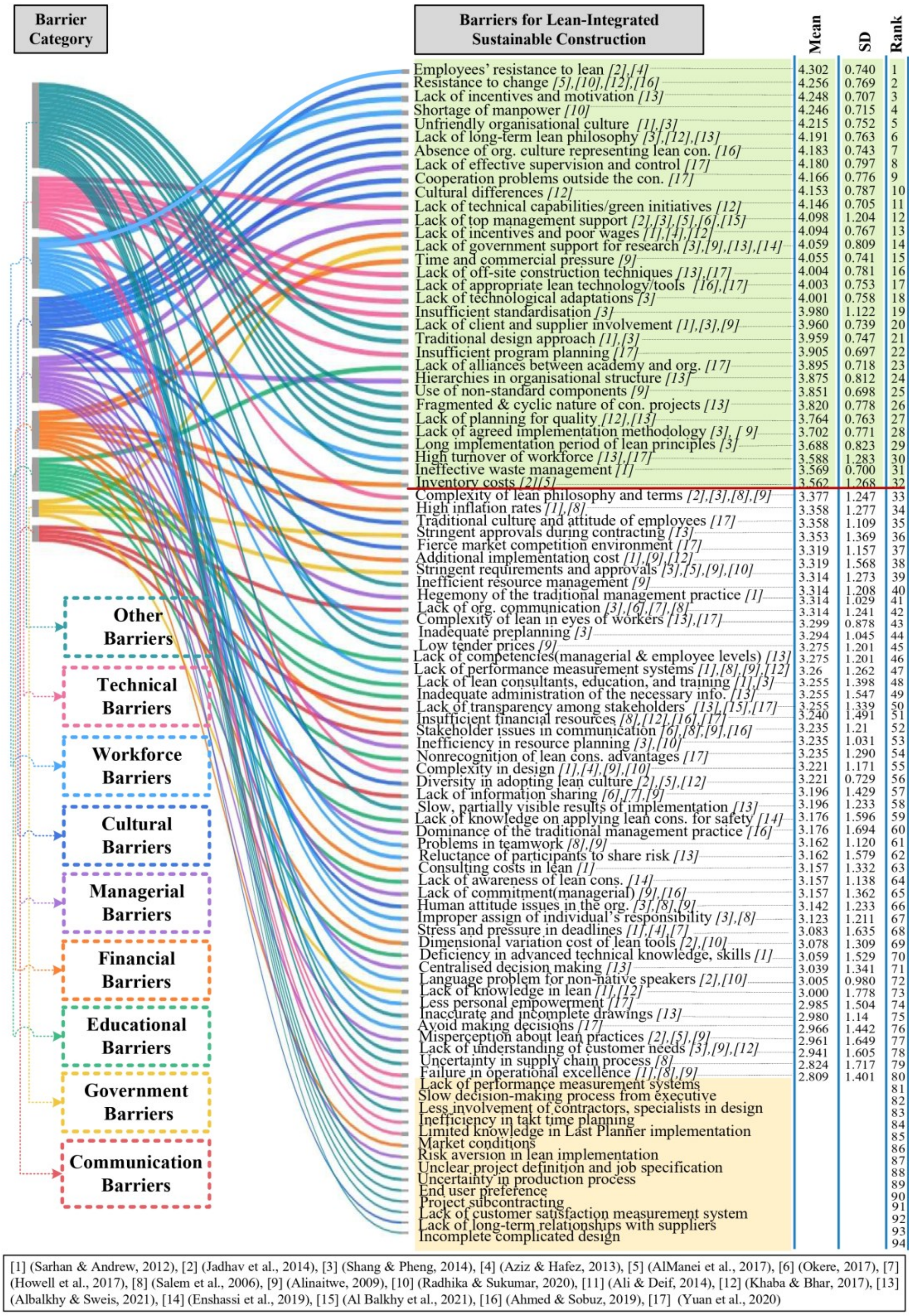

Figure 2: Barriers of lean integrated sustainable construction

To deepen the analysis of challenges in lean integrated sustainable construction, the identified key barriers were clustered according to the categories identified in the literature, as illustrated in Figure 3 below.

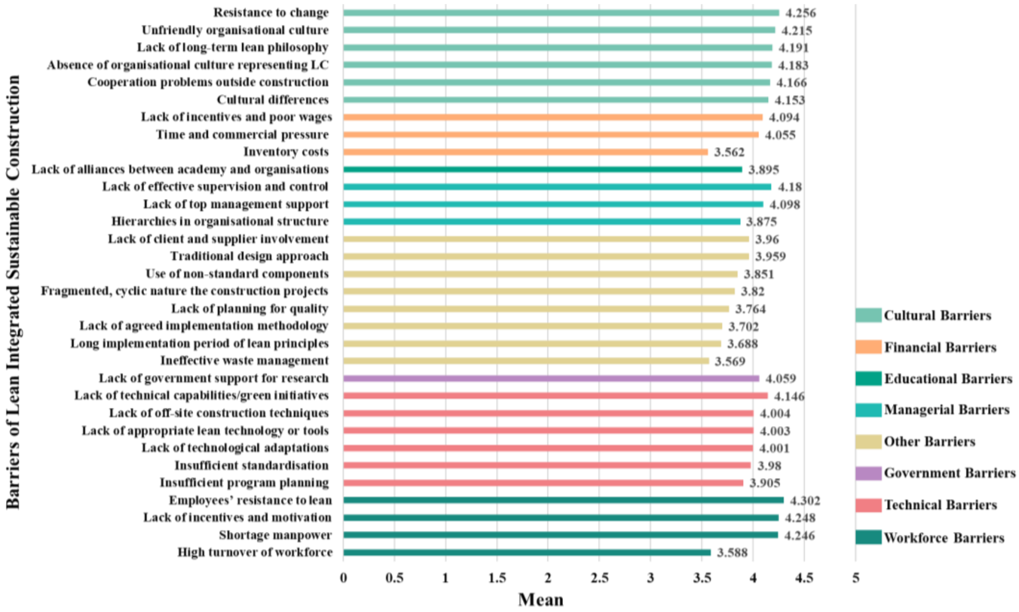

Figure 3: Clustering of key barriers of lean integrated sustainable construction

The visual clustering reveals a clear dominance of socially rooted barriers across the highest rated challenges. Cultural barriers such as resistance to change, and unfriendly organisational culture consistently ranked among the most critical, alongside workforce issues like low motivation, high turnover, and skill shortages. Managerial barriers particularly lack of top management support and ineffective supervision also emerged prominently. These clusters demonstrate that the core impediments to lean integrated sustainable construction are not technical or procedural in isolation but rather embedded in the organisational mindset, human behaviour, and leadership practices. Crucially, the interconnectedness of these categories reflects their shared foundation in broader social dimensions, because cultural, managerial, workforce, and educational barriers are not merely operational or technical; they are deeply rooted in the broader social fabric. This confirms the centrality of human dimensions in advancing sustainable construction.

5. DISCUSSION

As indicated in the lower section of the barriers in Figure 2, the study identifies 14 barriers to lean integrated sustainable construction, in addition to the 80 barriers identified in the literature. Moreover, the empirical findings of the study align closely with the literature findings, affirming that the most critical barriers to lean integrated sustainable construction are deeply embedded within social, human dimensions. The prominence of barriers such as employee resistance to lean, resistance to change, and lack of motivation strongly resonate with the conclusions of Moradi and Sormunen (2023), who assert that "people are the main root cause of the barriers, enablers, and implications of lean construction adoption." Similarly, the dominance of cultural, managerial, and workforce-related barriers in the findings corroborates the categorisations offered by Demirkesen et al. (2019) who identified these social categories as core impediments to lean integrated sustainable construction. The finding that technical or project-specific barriers ranked significantly lower aligns with the view of Sarhan and Andrew (2012), who argued that lean failure often stems not from technical deficiencies, but from inadequacies in leadership, training, and cultural readiness. Furthermore, Alinaitwe (2009) supported this narrative by underlining the persistent organisational and managerial constraints that hinder lean integration, despite its acknowledged benefits. Collectively, these parallels confirm that the empirical insights generated in this research are not isolated but rather form part of a broader, consistent pattern within contemporary construction literature.

5.1 IMPLICATIONS OF THE RESEARCH

This study significantly contributes to the theoretical understanding of the barriers impeding the successful integration of lean integrated sustainable construction. By identifying 32 critical barriers, with a focus on social aspects, the study offers new insights into the complex interplay of behavioural, managerial, and workforce challenges in lean thinking. From a practical standpoint, the study highlights the critical barriers that practitioners and organisations must address to successfully implement lean practices in sustainable construction projects. Collectively, organisations can utilise these findings to tailor their lean implementation strategies, focusing on human resource development, cultural realignment, and leadership engagement for more sustainable outcomes.

5.2 THE WAY FORWARD

The identified human-centric barriers present opportunities for future research to examine their impact in real-world construction settings. Researchers can further investigate how factors like leadership, culture, and workforce engagement influence the success of lean integrated sustainable construction adoption. These insights can contribute to developing an integrated framework for assessing organisational readiness and maturity in implementing lean integrated sustainable construction.

6. CONCLUSIONS

Green building is a key enabler of sustainable construction, as it translates sustainability principles into measurable practices focused on environmental performance, energy efficiency, and resource optimisation. When integrated with lean construction, it creates a comprehensive approach to achieving sustainability in the construction industry. This study reveals that the primary obstacles to successful lean integrated sustainable construction implementation are rooted in organisational culture and human factors. Key challenges include resistance to change, insufficient leadership, and misaligned incentive structures, all of which hinder the adoption of lean integrated sustainable construction. These findings emphasise the need of fundamental shift in organisational mindset, prioritising cultural adaptation, stakeholder collaboration, and continuous education. By addressing these human centric barriers, the construction sector can unlock the full potential of lean integrated sustainable construction, paving the way for more sustainable and efficient project delivery. Future research should explore practical frameworks for creating organisational readiness and overcoming cultural resistance to these innovative approaches. Strengthening the alignment between green building practices and lean thinking will not only improve environmental and economic outcomes but also contribute to long-term industry resilience. As the demand for sustainable infrastructure continues to rise, this integrated approach stands as a critical pathway toward achieving global sustainability targets and transforming the construction industry's future.

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