Lean construction and sustainability: a review of research trends and implications for the United Nations SDGs

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Abstract. Lean Construction has emerged as a transformative approach in the construction industry, emphasizing efficiency, waste reduction, and continuous improvement. This review presents a bibliometric analysis of Lean Construction research from the past two decades, focusing on the evolution, core themes, and contributions to sustainable development. Using the Scopus database and VOSviewer, 4,905 documents were analyzed to identify the most relevant keywords, key research trends, and their alignment with the United Nations Sustainable Development Goals (SDGs). The analysis revealed that Lean Construction is closely linked with concepts such as waste management, sustainability, project management, and Building Information Modeling (BIM), underscoring its potential to contribute to SDG 9 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), and SDG 12 (Responsible Consumption and Production). The study also highlights the challenges of global implementation, such as varying construction practices, resistance to change, and limited access to technology in certain regions. Despite these challenges, the integration of Lean principles offers significant opportunities to improve efficiency and sustainability in the construction sector.

1 Introduction

The construction industry is renowned for its complexity and susceptibility to inefficiencies, often characterized by fragmented processes, resource wastage, and project delays (1, 2). In response to these challenges, Lean Construction has emerged as a transformative approach aimed at enhancing productivity, reducing waste, and improving project outcomes (3-5). Rooted in the principles of Lean Manufacturing introduced by Toyota in the mid-20th century, Lean Construction adapts these principles to the unique demands of the construction sector, promoting a culture of continuous improvement, collaboration, and value maximization (6-8).

Lean Construction focuses on the systematic identification and elimination of non-value-adding activities, aiming to streamline processes and integrate project delivery (9-11). By

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emphasizing the optimization of workflows, reduction of waste, and enhancement of overall project efficiency, Lean Construction seeks to address the inherent inefficiencies and challenges of traditional construction methods (12, 13). This approach fosters a more cohesive and integrated project environment, which can lead to significant improvements in both cost and time performance (14).

In recent years, Lean Construction has gained recognition for its significant contributions to sustainability (15-17). By promoting efficient use of resources and minimizing waste, Lean Construction inherently supports environmentally friendly practices (18-20). This focus on reducing material consumption and energy use aligns with broader sustainability objectives, contributing to more sustainable construction practices and reducing the environmental impact of building projects (18, 21).

This review aims to conduct a bibliometric analysis of keywords in Scopus-indexed articles on Lean Construction. By analyzing keyword data, the review seeks to map key research themes, identify prevalent terms, and explore their connections to Lean Construction. The analysis will highlight how these keywords reflect the scope of Lean Construction research and its alignment with sustainability practices. The goal is to provide a detailed overview of the key topics and trends within Lean Construction, offering insights into how the field addresses sustainability and identifying potential areas for further research.

2 Methodology

This bibliometric analysis is based on a comprehensive search conducted in the Scopus database, focusing on the keyword "Lean Construction." The search encompassed the article title, abstract, and keywords fields to capture a broad range of relevant literature. A total of 4,905 documents were retrieved, including journal articles, conference papers, and reviews. The study examines publication trends over the last 24 years, highlighting the annual growth in research output. The data reveals a significant increase in publications over this period, indicating growing interest and research activity in Lean Construction. The early years of the analysis, particularly from 2005 to 2007, show a relatively low number of publications, with only 10 documents recorded in 2005. However, a gradual increase is observed from 2008 onwards, reflecting the broader adoption and integration of Lean Construction principles in academic and practical contexts. The growth in publications is particularly notable from 2015 onwards, with a substantial rise in both the quantity and diversity of topics covered. The peak year is 2019, which saw 378 documents published, followed by a slight decline in subsequent years. In 2022, there were 375 documents published, while the numbers slightly decreased to 362 and 286 in 2023 and 2024, respectively. This trend suggests a steady but slightly fluctuating research interest in recent years. **Figure 1** provides an overview of the number of documents published each year from 2005 to 2024, illustrating the significant increase in research output and the overall trends in Lean Construction research.

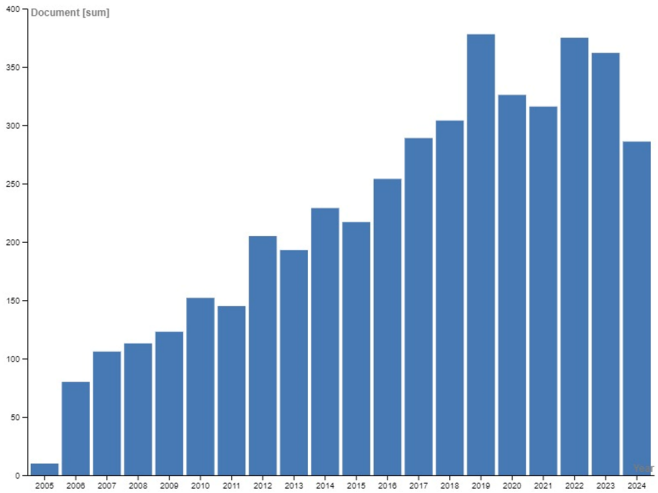

Fig. 1. Annual publications on Lean Construction (2005-2024).

To narrow the scope and promote the specificity of this review, the selection criteria were refined to focus on 549 documents. These documents are limited to the subject area of engineering, are in English, and are classified as journal articles in their final publication stage. All selected articles are open access, ensuring unrestricted availability and facilitating a comprehensive analysis of Lean Construction research within the engineering discipline. This refined dataset provides a more targeted understanding of the current state of the field, emphasizing high-quality, peer-reviewed contributions that are readily accessible to researchers and practitioners. For a detailed analysis and visualization of the data, VOSviewer, a sophisticated bibliometric software tool, was employed. VOSviewer enables the creation of bibliometric networks and offers comprehensive visual representations of research trends, co-authorship, and keyword co-occurrence. By utilizing VOSviewer, this study was able to map the intellectual structure of Lean Construction research, revealing prominent authors, influential articles, and collaborative networks. The software's capabilities in generating network maps and clusters facilitate a deeper understanding of the interconnections between research topics and the evolution of the field over time. This analysis provides valuable insights into key research themes and influential contributors, offering a nuanced perspective on the Lean Construction research landscape.

3 Results and Discussion

3.1 Results

Using VOSviewer for a detailed bibliometric analysis, a co-occurrence analysis was conducted with the parameters set to "co-occurrences," "all keywords" as the unit of analysis, and "full counting" as the counting method, with a minimum occurrence threshold of 1. This analysis revealed a total of 4,172 unique keywords that met the threshold, highlighting the breadth and diversity of research topics within Lean Construction. The most frequently occurring keywords include "Lean Construction" with 177 occurrences and a total link strength of 734, followed by "Construction Industry" with 103 occurrences and a total link strength of 565. Other prominent keywords are "Lean Production" (99 occurrences, 622 link strength), "Project Management" (84 occurrences, 526 link strength), and "Construction" (63 occurrences, 376 link strength). These keywords represent the core focus areas within the

Lean Construction literature, emphasizing not only the primary concept of Lean Construction itself but also its application in the broader context of the construction industry, lean production principles, and project management practices. The high total link strength of these keywords indicates their significant interconnectedness and centrality within the research field, serving as key thematic nodes around which much of the literature is clustered, as seen in **Figure 2**.

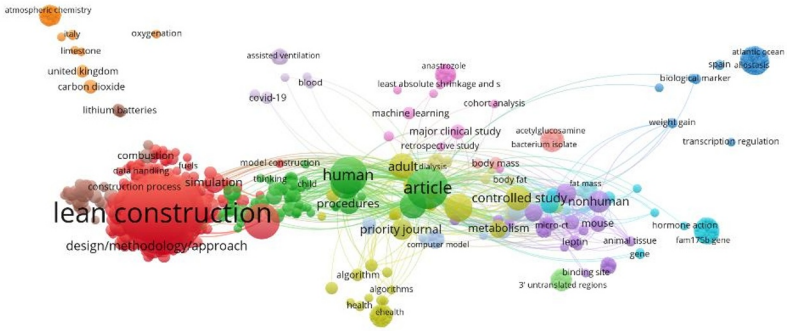

Fig. 2. Keyword co-occurrence network by VOSviewer

To gain a clearer understanding of the connections between "Lean Construction" and other research topics, the minimum occurrence of a keyword was set to 5 in the VOSviewer analysis. This refined approach reveals the most significant associations and highlights the central themes within the field. The analysis indicates that "Lean Construction" is closely connected with keywords such as "lean," "waste," "sustainability," "building," and "building information modeling." Additionally, it is linked with terms like "construction planning," "safety," "efficiency," "waste management," "construction project planning," "simulation," "construction management," "architectural design," and "human." These connections illustrate the multifaceted nature of Lean Construction research, encompassing various aspects of construction practices, project management, and sustainable development, while also emphasizing the integration of innovative technologies like building information modeling (BIM) and the focus on improving efficiency and safety in the construction industry.

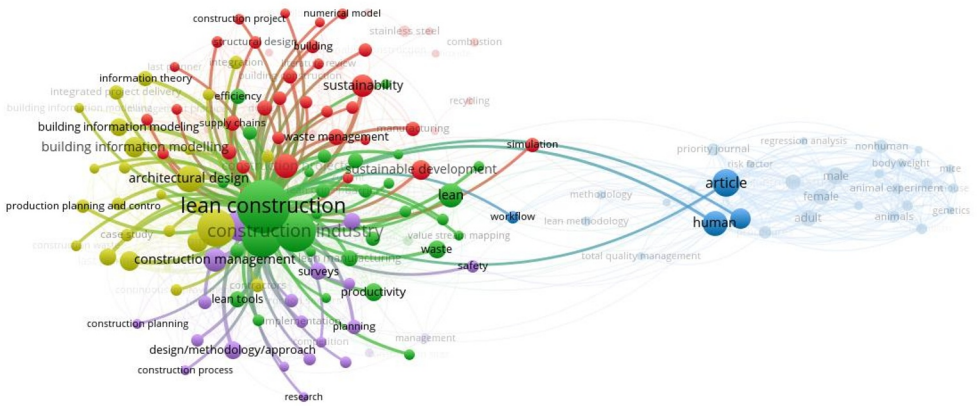

Fig. 3. Lean Construction's connections with related keywords.

3.2 Discussion

3.2.1 Integrating lean construction with Sustainable Development Goals (SDGs)

The keyword analysis reveals a diverse set of terms connected to "Lean Construction," including "lean," "waste," "sustainability," "building," and "building information modeling (BIM)," among others. These connections reflect the expansive scope of Lean Construction research and its potential contributions to sustainable development and the United Nations Sustainable Development Goals (SDGs).

The strong link between "Lean Construction" and "waste" underscores the fundamental principle of lean thinking, which aims to eliminate waste and improve efficiency in construction processes. This focus directly contributes to SDG 12, "Responsible Consumption and Production," by promoting resource efficiency and reducing the environmental footprint of construction activities. Lean Construction strategies, such as just-in-time delivery and pull planning, help minimize material waste, reduce project delays, and lower overall costs, thus contributing to more sustainable building practices.

"Sustainability" is another prominent keyword connected to Lean Construction, highlighting the growing emphasis on integrating sustainable practices into the construction industry. Lean Construction promotes the efficient use of resources, reducing energy consumption and environmental impact, aligning with SDG 9, "Industry, Innovation, and Infrastructure," and SDG 11, "Sustainable Cities and Communities." By fostering innovative practices and improving the efficiency of construction processes, Lean Construction supports the development of sustainable infrastructure and resilient communities.

The association with "building information modeling (BIM)" illustrates the increasing adoption of digital technologies to support Lean Construction practices. BIM enables better project visualization, coordination, and collaboration, reducing errors and rework, which contributes to more sustainable construction practices. This aligns with SDG 9, as the use of technology and innovation improves the efficiency and sustainability of infrastructure projects. Other keywords such as "construction planning," "safety," and "efficiency" reflect the operational aspects of Lean Construction, focusing on improving project delivery, ensuring worker safety, and enhancing productivity. These aspects contribute to SDG 8, "Decent Work and Economic Growth," by promoting safe and productive work environments and supporting sustainable economic growth through efficient resource use and reduced operational costs. The keyword "human" suggests an interest in the social dimensions of Lean Construction, such as worker well-being, collaboration, and stakeholder engagement. This focus on the human element is crucial for achieving SDG 3, "Good Health and Well-being," and SDG 8, as it promotes safe, healthy, and equitable working conditions in the construction sector.

Overall, the interconnectedness of these keywords with "Lean Construction" indicates that the field has a significant role to play in advancing multiple SDGs. By focusing on waste reduction, resource efficiency, technological integration, and human well-being, Lean Construction practices contribute to the sustainability of the built environment and support the global agenda for sustainable development.

3.2.2 Challenges and opportunities in implementing lean construction practices globally

While Lean Construction offers significant benefits in terms of efficiency, waste reduction, and sustainability, its global implementation faces several challenges that warrant discussion. One of the primary obstacles is the variability in construction practices and regulatory environments across different regions. In many developing countries, traditional construction

methods, limited access to advanced technologies, and lack of skilled labor can hinder the adoption of Lean principles. Additionally, resistance to change and a lack of awareness or training in Lean methodologies can impede their widespread acceptance within the industry. However, these challenges also present opportunities. For example, tailored training programs and capacity-building initiatives can be developed to educate stakeholders on the benefits of Lean Construction, especially in contexts where resource efficiency and cost management are critical. Moreover, international collaborations and knowledge exchange can help bridge the gap, enabling the transfer of best practices and innovative solutions across borders. The integration of digital tools like Building Information Modeling (BIM) and data analytics in Lean Construction can also accelerate its adoption, providing a more robust framework for project planning and management. By addressing these challenges and leveraging these opportunities, the construction industry can advance the global implementation of Lean practices, ultimately contributing to more sustainable and resilient infrastructure worldwide.

3.2.3 The role of lean construction in promoting collaboration and communication

Another critical aspect of Lean Construction is its potential to transform collaboration and communication within construction projects. Traditional construction projects often suffer from fragmented communication, siloed information, and a lack of coordination among various stakeholders, leading to delays, cost overruns, and quality issues. Lean Construction, with its emphasis on collaborative planning and transparency, seeks to overcome these challenges by promoting a culture of open communication and teamwork.

Techniques such as the Last Planner® System, pull planning, and collaborative scheduling engage all project participants, including contractors, subcontractors, and suppliers, in the planning process. This collaborative approach ensures that everyone has a clear understanding of the project timeline, resource requirements, and potential constraints, reducing misunderstandings and improving workflow. Additionally, the use of visual management tools and regular check-ins enhances real-time communication, enabling teams to identify and address issues proactively. Improved collaboration not only leads to more efficient project delivery but also supports a more inclusive and equitable work environment. By involving all stakeholders in decision-making processes, Lean Construction fosters a sense of ownership and accountability, which can boost morale and job satisfaction. This inclusive approach aligns with the principles of SDG 8, "Decent Work and Economic Growth," by creating better working conditions and promoting a collaborative and respectful work culture. Ultimately, the emphasis on communication and collaboration in Lean Construction can lead to more successful projects, higher-quality outcomes, and stronger relationships among project participants.

4 Conclusion

This review provides a comprehensive bibliometric analysis of Lean Construction research over the past two decades, highlighting its evolution, core themes, and contributions to sustainable development. The analysis, conducted using VOSviewer, reveals that Lean Construction has grown significantly in both scope and depth, with a substantial body of literature emphasizing key areas such as waste reduction, project management, and the integration of advanced technologies like Building Information Modeling (BIM). Lean Construction's alignment with the principles of sustainability and its potential contributions to the United Nations Sustainable Development Goals (SDGs) are particularly noteworthy. The emphasis on minimizing waste, promoting efficiency, and improving resource utilization directly supports SDG 12, “Responsible Consumption and Production.” Furthermore, the

integration of lean practices in construction projects promotes sustainable infrastructure development, aligning with SDG 9, "Industry, Innovation, and Infrastructure," and SDG 11, "Sustainable Cities and Communities."

However, the global implementation of Lean Construction faces challenges, including variability in construction practices, resistance to change, and limited access to training and technology in certain regions. Addressing these challenges through education, international collaboration, and technology integration presents significant opportunities to expand the adoption of Lean principles worldwide.

In conclusion, Lean Construction emerges as a critical framework for advancing sustainable construction practices. Its focus on efficiency, collaboration, and innovation can help reshape the construction industry, driving it towards more sustainable and resilient outcomes that align with global sustainability goals. Future research should continue to explore strategies for overcoming implementation barriers and further integrating Lean Construction principles with sustainable development frameworks to maximize their impact on the built environment.

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