CHAPTER 138

Synergizing Lean Construction, Building Information Modeling, and Sustainability: A Comprehensive Review and Integration Analysis in Building Construction Projects

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ABSTRACT

The Architecture, Engineering, and Construction (AEC) industry faces labor inefficiency, environmental issues, and productivity difficulties. To improve project outcomes, this study investigates the integration of sustainability concepts, lean construction (LC), and building information modeling (BIM). Although interest in LC and BIM separately is expanding, there is still a dearth of research on their combined use. By outlining the benefits of BIM and suggesting standard operating procedures, this article seeks to close this disparity. The study proposes to undertake a systematic literature review using the PRISMA approach. In response to this challenge, a lot of research has been carried out to ensure effectiveness and efficiency in the building industry. Consequently, this study seeks to analyze the integration of Lean Construction (LC) and Building Information Modeling (BIM) in the building industry. This systematic literature review was done using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) method to stringently identify, sort, and examine pertinent information from journals, conferences, and reports. By the integration of evidence in the systematic review of literature, this study aims to make notable contributions to diverse methods, techniques, challenges, and opportunities of integrating Lean Construction and BIM in construction.

Keywords: BIM; Lean construction; Sustainability; Bim and lean integration.

1.0 Introduction

1.1 Background

Among several industries that depend heavily on labor, the architecture, engineering, and construction (AEC) sector struggles with low productivity and inefficient labor practices. Adverse environmental effects and resource waste are also major societal issues. This indicates that it is essential to address the issue of how to maintain both competitiveness and profitability by making the best use of all their resources, including people, machinery, supplies, and technology. This is also consistent with lean thinking. A growing number of academics and government agencies are becoming interested in cutting-edge techniques and approaches like BIM project management and Lean construction management (LCM), as awareness of low-carbon development and ecological conservation grows (Ballard & Howell, 2003).

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Globally, the construction sector has been distinguished by poor productivity: between 1995 and 2015, the average growth rate of value added per person was only 1.0%, whereas the overall growth rate of the economy was 2.7% (Hei *et al.*, 2024). In contrast, the manufacturing sector grew at a rate of roughly 3.6% over the same period. This productivity disparity emphasizes the necessity of creative solutions to raise productivity and performance in the AEC sector. Despite these initiatives, research on the requirements for successfully implementing lean concepts with BIM in the AEC sector is still lacking. While earlier research has emphasized the advantages and difficulties of applying lean construction techniques to fully realize the potential synergies between BIM individually, it is necessary to investigate the integration of these two methodologies. By establishing standards for the application of lean concepts using BIM, this study seeks to close this research gap and tackle the research challenge in its entirety. (Ong & Pheng, 2021)

Given these challenges and opportunities, this research aims to develop a structured approach to integrating Lean principles with BIM, focusing on best practices, implementation frameworks, and the identification of key success factors. By exploring case studies and analyzing empirical data, this study will contribute to a deeper understanding of how Lean-BIM integration can be leveraged to enhance project efficiency, sustainability, and overall performance in the AEC sector. The findings will be valuable for construction firms, policymakers, and researchers seeking to bridge the gap between theoretical concepts and practical applications in modern construction management.

1.2 Aim and objectives

To explore the integration of Lean Construction (LC) and Building Information Modelling (BIM) through a systematic literature review to identify major benefits, challenges, and future research directions.

1.3 Objectives

- To identify research papers, and journals on the integration of Last Planner System and BIM using PRISMA.
- To analyze the theory, contextual background, characteristics, and methodologies used in the studies.

1.4 Scope

The study will encompass peer-reviewed research papers, journal articles, and conference papers sourced from online databases such as Scopus, Web of Science, and Research Gate, all written in English. The literature review will concentrate on recent publications from the past 15 years to understand the development and progress in the integration of Building Information Modelling (BIM) and Lean Construction (LC). The primary focus will be on the construction industry in India, with additional coverage of select papers from other countries to evaluate the efficiency of this integration and identify existing barriers. While the study will not propose a framework for integration, it will suggest areas for further research.

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2.0 Literature Review

The AEC industry has observed significant changes in efficiency and project management skills by adopting methodologies such as Lean Construction and Building Information Modelling (BIM). Lean Construction principles, derived from manufacturing principles, focus on eliminating waste, optimizing workflows, and ensuring continuous improvement. Building information models in the AEC industry makes wonderful and efficient digital 3D models to successfully integrate and manage project management information throughout the construction project lifecycle. The integration and adaption of these two methodologies present an opportunity to enhance productivity, reduce errors, and improve overall project performance. Therefore, the potential benefits and challenges remain in effectively merging Lean and BIM into a balanced system.

2.1 Lean construction (LC)

Lean Construction (LC) is a spin-off of the lean manufacturing philosophy led by Toyota in the 1950s and codified as the Toyota Production System (TPS). The philosophy emerged again in the 1980s and was subsequently termed "lean production" by Womack *et al.* (1995). LC targets eliminating waste, streamlining workflow efficiency, and maximizing value using tools such as Percent Plan Completion (PPC) (The Lean-to-Green Evolution, 2019). Developed by the Lean Construction Institute (LCI) in 1993, LC combines the lean production philosophy with construction management to enhance the performance of a project and minimize inefficiencies.

2.2 Building information modelling (BIM)

Building Information Modelling (BIM) is a revolutionary computer program that facilitates project coordination in the Architecture, Engineering, and Construction (AEC) sector. The National Building Information Modelling Standards (NBIMS) defines BIM as a shared platform via which stakeholders can input, modify, and review data throughout the entire life of a building (Azhar *et al.*, 2012). Utilization of BIM leads to improved visualization, less design conflicts, and enhanced cost estimation, thereby resulting in higher-quality outcomes in projects. In combination with the integration of lean construction principles, BIM ensures maximum utilization of materials, workflows, and rework, which all contribute positively to overall resource management.

2.3 Sustainable development in construction projects

Sustainable construction confronts the AEC sector's EES footprint through the motivation of natural resource utilization efficiency and minimization of negative effects on the environment. With its roots in the United Nations' SDGs, it involves eco-similar materials, renewable energy sources, and innovative design options such as green roofs and passive cooling (Bajjou *et al.*, 2017). Standards like Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM) provide guidelines for sustainable practices. Further, Building Information Modelling (BIM) and Artificial Intelligence (AI) facilitate optimal utilization of resources and life cycle assessment. However, factors like high capital expenses, change resistance, and absence of trained manpower are still preventing it from gaining widespread acceptance.

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3.0 Research Methodology

3.1 Systematic literature Review using PRISMA

The PRISMA methodology is a systematic and explicit approach that involves the collection, and evaluation of data and uses methodical procedures to identify, select, evaluate, and review relevant studies (Sharma & Laishram, 2024). To maintain methodological rigor, this study also follows PRISMA for systematic review focusing on BIM-Lean integration in the construction industry and was performed in three stages-

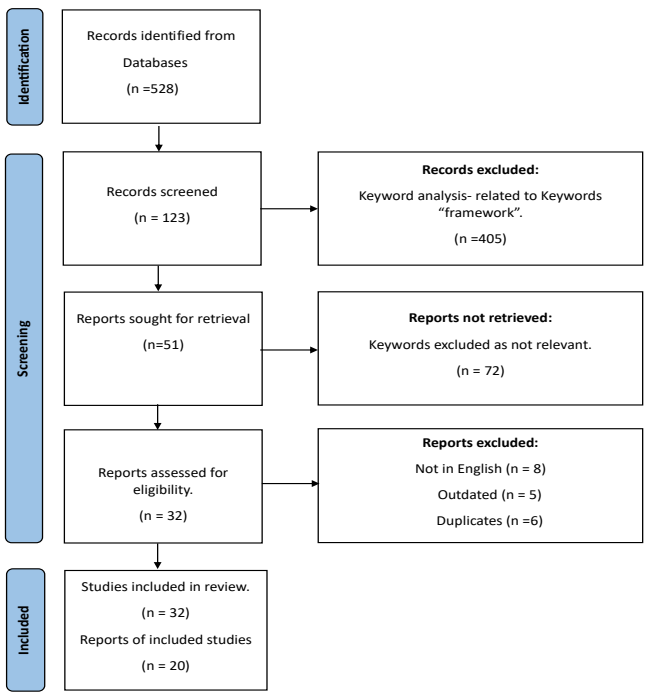
Stage I – planning the review.

Stage II – conducting the review.

Stage III – analyzing and reporting the review

The flowchart (Figure 1) illustrates the step-by-step selection process for research studies. Initially, a total of 528 studies were identified. However, the majority (405 studies) were excluded as they did not pertain to the topic. This left 123 studies for further examination. Subsequently, 51 studies were thoroughly reviewed, while 72 were eliminated for being unhelpful. After that, 32 studies underwent scrutiny. Some were discarded because they were not in English (8), were outdated (5), or were duplicates (6). 12 Ultimately, 32 studies were selected, with 20 being the most significant. This procedure allowed for the identification of the best and most relevant studies for the research.

Figure 1: Systematic Literature Review using PRISMA



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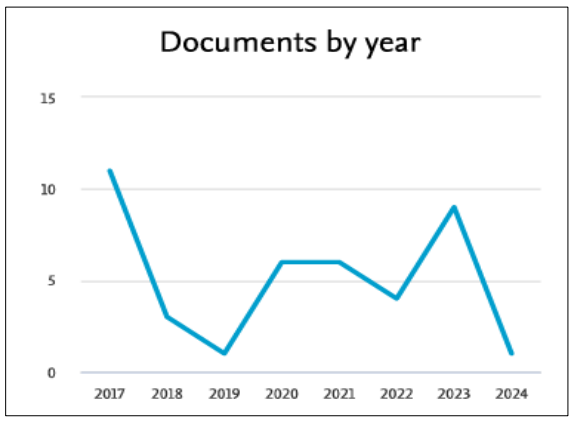
4.0 Results and Discussion

Based on the detailed method as stated in the earlier section, the results are discussed as follows: The result first addresses the bibliometric profile of the studies (i.e., publication, authorship, citation).

4.1. Publication trends over time

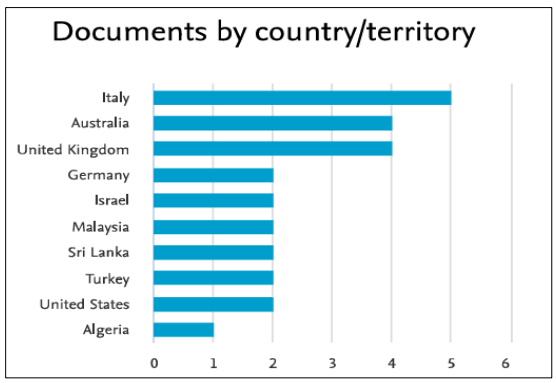
The analysis of the data showcases the distribution of published documents over the selected period, highlighting key trends in BIM, Lean Construction, and Sustainability research. The graph indicates two distinct phases of increased interest in these areas, with a significant rise in 2017 and another peak in 2023. These fluctuations reflect the growing adoption of digitalization (BIM), efficiency-driven methodologies (Lean), and environmentally conscious practices (Sustainability) in the construction industry**.**

Figure 2: Publication Over the Years



Source: Scopus

Figure 3: Publication by Country



Source: Scopus

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4.2. Publication by country

Developed countries such as Italy, Australia, and the United Kingdom have a higher number of research publications on this topic compared to developing nations like Malaysia, Sri Lanka, and Algeria. This disparity may be attributed to various factors, with one major reason being resistance to change among stakeholders in emerging economies, which affects the adoption of new methodologies and technologies**.**

4.3 Keyword co-occurrence analysis

The cluster shown in Figure 3 is a network map generated with VOS viewer, illustrating the connections among key concepts associated with Building Information Modelling (BIM), Lean Construction, and their synergy within the construction sector. The nodes signify various themes, while the connecting lines depict the relationships between these subjects. Different hues presumably correspond to publication years or thematic groups, as demonstrated by the color gradient in the bottom right corner, spanning from 2020 to 2023.

Figure 4: Mapping of Co-occurrence of Keywords

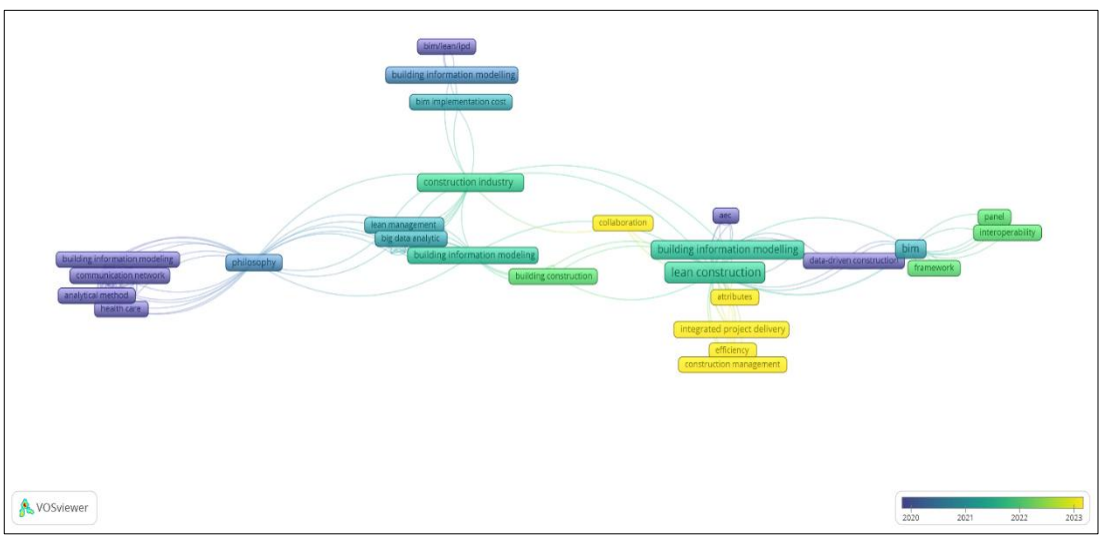

Figure 4 emphasizes the connections between BIM and Lean Construction in contemporary construction methodologies. Central themes such as efficiency, collaboration, integrated project delivery, and data-driven construction are highlighted as significant focal points. The network further investigates implementation costs, interoperability, and sustainable practices related to BIM adoption. The color change illustrates the progression of research interests over time, revealing a growing focus on framework development, construction management, and digital transformation. This map acts as a valuable representation of recent developments and research directions within the field.

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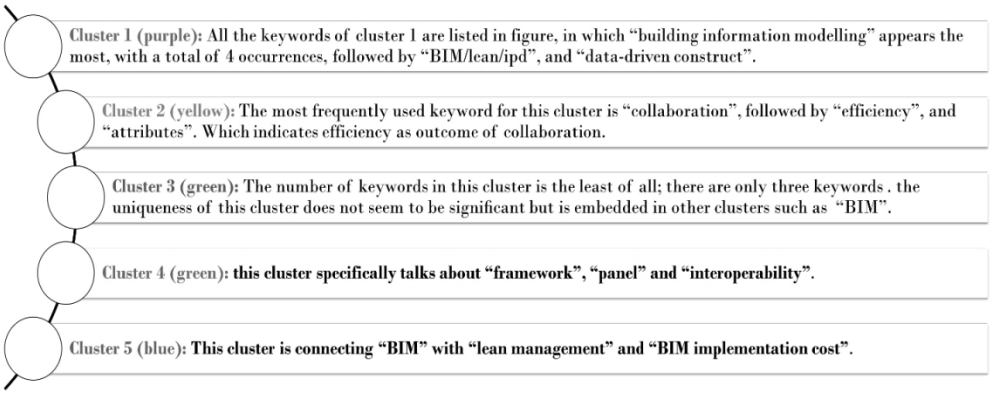
Figure 5: Inferences of the Cluster of Keywords



5.0 Conclusion

This research has widely examined the intersection of Lean Construction (LC), Building Information Modeling (BIM), and Sustainability in construction projects. The results point out that although each method alone helps in achieving maximum project efficiency, minimizing waste, and enhancing sustainable practice, their application in combination has a revolutionary potential for the Architecture, Engineering, and Construction (AEC) sector. Lean Construction promotes a culture of waste reduction, resource utilization, and process improvement. BIM is a virtual facilitation technology that improves visualization, communication, and anticipatory decision-making. Sustainability norms govern that the way construction is done becomes harmonized with ecology, economy, and social harmony, enabling wiser and cleaner infrastructure. Despite these advantages, change resistance, increased cost of implementation, and professional pressure are the limiting factors toward massive application. There is a need for future studies to bridge the gaps through the integration of the framework, technological advancement in digitization, and policy-level dissemination of sustainable construction. Through assistance from technological revolutions and interdisciplinary approaches, the AEC industry has the potential for greater efficiency, cost-effectiveness, and sustainability.

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