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Lean Construction as an Efficiency Strategy for Sustainable Infrastructure: A Systematic Literature Review

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ABSTRACT: The construction industry continued to face major challenges related to inefficiency, resource waste, and significant environmental impacts. These issues highlighted the urgent need for more effective project management strategies to support sustainable infrastructure development. This study aimed to synthesize existing knowledge on the role of Lean Construction (LC) as an efficiency strategy in achieving sustainable infrastructure, while also identifying research gaps related to digital integration and the circular economy. A Systematic Literature Review (SLR) was conducted on 433 publications indexed in Scopus between 2015 and 2025. After applying inclusion and exclusion criteria as well as a quality assessment framework, 14 articles were selected for detailed analysis. The findings indicated that 71.4% of the reviewed studies emphasized LC integration with sustainability and digital technologies, particularly Building Information Modeling (BIM) and digital twins. Waste reduction (64.3%), cost efficiency (57.1%), time efficiency (50%), and implementation barriers (42.9%) also emerged as dominant themes. However, the integration of LC with Circular Economy (CE) principles, such as reuse, recycling, and design for deconstruction, remained limited. Furthermore, the social dimension of sustainability, including occupational safety, labor welfare, and collaborative culture, received minimal empirical attention. This study concluded that LC had significant potential to enhance project efficiency and sustainability, but its application was still predominantly conceptual, with limited validation in developing countries. Recommendations included expanding empirical field studies in the Global South, strengthening LC–BIM–CE integration in practice, developing practical tools and matrices to support implementation, and promoting regulatory frameworks that enable wider adoption.

KEYWORDS: Lean Construction; efficiency; waste reduction; sustainable infrastructure; bim; circular economy.

1. Introduction

The construction industry has long been associated with persistent inefficiencies in cost, time, and resource utilization. Globally, nearly one-third of total solid waste originates from construction, demolition, and renovation activities, making the sector a major contributor to environmental degradation [1–3]. These challenges were especially critical in developing countries, where weak regulatory frameworks, limited waste management infrastructure, and economic barriers exacerbated environmental and social impacts [4, 5]. Within the context of sustainable development, these conditions highlighted the need for adaptive and efficient project management strategies that could enhance performance while minimizing negative externalities [6, 7].

Lean Construction (LC) emerged as a key strategy to address such inefficiencies by promoting waste minimization, workflow optimization, and continuous improvement throughout the project life cycle. Core lean principles, such as eliminating non-value-adding activities, increasing process transparency, and enhancing stakeholder collaboration, were shown to improve project efficiency [8]. Tools including the Last Planner System (LPS), Value Stream Mapping (VSM), and Just-In-Time (JIT) were widely applied to enhance planning reliability and reduce material waste. The integration of LC with digital technologies, particularly Building Information Modeling (BIM), further improved coordination among project teams, reduced costs, and increased efficiency by 25–35% [9, 10].

In Indonesia, inefficiencies remained prevalent due to poor project management practices, weak coordination among stakeholders, and inadequate material handling [11]. Studies indicated that material recovery and recycling could reach 40–60%, yet the lack of comprehensive regulatory frameworks and underdeveloped industry practices hindered this potential [12]. Although the Ministry of Public Works and Housing (PUPR) promoted BIM implementation, adoption in both public and private sectors faced challenges related to limited human resource capacity, regulatory gaps, and organizational resistance [13]. These factors underscored the importance of exploring LC integration with BIM and Circular Economy (CE) principles as a pathway to improving efficiency and sustainability in developing countries [14].

Beyond cost and time efficiency, LC contributed to broader sustainability objectives. Previous research showed that lean practices could reduce the environmental footprint of construction projects by 18–24% through energy savings, waste reduction, and improved resource efficiency [15, 16]. Economically, LC minimized operational costs, while socially it enhanced worker safety, labor welfare, and productivity [17]. When combined with frameworks such as Life Cycle Assessment (LCA), LC demonstrated strong potential to support long-term sustainable infrastructure [18].

Recent studies suggested that integrating LC with advanced digital technologies, including BIM, the Internet of Things (IoT), and digital twins, could strengthen CE strategies through data-driven material planning, design for disassembly, and material traceability [19, 20]. However, most existing research remained conceptual, with limited empirical validation, particularly in developing countries [21].

Given these conditions, this study addressed the lack of empirical evidence on LC–BIM–CE integration in developing contexts. Its novelty lay in synthesizing how Lean Construction contributed to efficiency and sustainability while examining its intersection with digital transformation and circular economy principles, an area still underexplored. Accordingly, this study aimed to: (1) synthesize current knowledge on LC as an efficiency strategy for sustainable infrastructure development; (2) identify dominant themes, methodologies, and research gaps related to CE and the social dimension of sustainability; and (3) propose contextual recommendations for implementing LC in developing countries [22–24].

2. Materials and Methods

This study adopted the Systematic Literature Review (SLR) approach as the primary research method. The SLR was selected for its ability to systematically identify, evaluate, and synthesize relevant research evidence in a transparent and replicable manner. This method was considered appropriate for academic investigations that aimed to answer research questions comprehensively through rigorous analysis of multiple scientific publications. As suggested by methodological guidelines [25], the SLR approach was effective in minimizing bias and enhancing the quality of evidence-based synthesis in engineering and technology research. The review process was structured into three stages: planning, conducting, and reporting.

In the planning phase, the scope of the study was defined using the PICo framework, which represents Population, Phenomenon of Interest, and Context. The population was defined as construction projects and industry stakeholders engaged in project management; the phenomenon of interest was the application of Lean Construction (LC) as a strategy to reduce waste and enhance performance; and the context was sustainable infrastructure development, emphasizing efficiency in cost, time, quality, and environmental performance. The detailed PICo framework applied in this study is presented in Table 1.

Table 1. PICo framework.

Criteria	Description
Population	Construction projects and industry stakeholders involved in project management
Interest	Application of Lean Construction as an efficiency strategy to reduce waste and improve project performance
Context	Sustainable infrastructure development focusing on cost, time, quality, and environmental impacts

During the conducting phase, a systematic search strategy was developed. The first step involved identifying keywords that reflected the research objectives. The keywords were grouped into three categories: the object of study (e.g., “construction industry,” “construction project,” “sustainable infrastructure”); the intervention or technology (e.g., “Lean Construction,” “Last Planner System,” “Value Stream Mapping,” “Just-In-Time,” “Lean tools,” “BIM integration,” “Lean Construction 4.0”); and the expected benefits or efficiency outcomes (e.g., “waste reduction,” “time optimization,” “cost savings,” “sustainability,” “resource efficiency,” “environmental impact reduction”). To ensure transparency, a Boolean search string was constructed and applied in Scopus as follows: ("Lean Construction" OR "Lean Project Management" OR "Lean Production" OR "Last Planner System" OR "Value Stream Mapping" OR "Just-In-Time") AND ("construction industry" OR "sustainable infrastructure" OR "infrastructure project") AND ("waste reduction" OR "efficiency" OR "sustainability" OR "cost savings" OR "resource efficiency" OR "environmental impact reduction"). Additional filters were applied to include only English-language publications published between 2015 and 2025. The same search string was adapted for Google Scholar to capture relevant gray literature and conference proceedings. The complete list of keywords used in the search process is summarized in Table 2.

Table 2. Keywords used in the search.

Topic	Keywords
Object of Study	"construction industry", "construction project", "infrastructure project", "sustainable infrastructure"
Intervention/Tech.	"Lean Construction", "Last Planner System", "Value Stream Mapping", "Just-In-Time", "Lean tools", "BIM integration", "Lean Construction 4.0"
Benefits/Efficiency	"waste reduction", "efficiency", "time optimization", "cost savings", "sustainability", "resource efficiency", "environmental impact reduction"

The primary database selected for this study was Scopus, due to its comprehensive coverage of peer-reviewed scientific publications. Additional searches were conducted in Google Scholar to capture supplementary and gray literature. To ensure the inclusion of recent research, only studies published between 2015 and 2025 were considered. The article selection process comprised three main stages: (1) an initial screening of titles and abstracts based on keyword relevance; (2) a full-text review of potentially eligible studies; and (3) a quality assessment based on predefined criteria. At each stage, duplicate records were removed, and the inclusion and exclusion criteria were rigorously applied. A PRISMA-style flow diagram (Figure 1) illustrates the overall screening and selection process for transparency. The inclusion and exclusion criteria adopted in this study are summarized in Table 3.

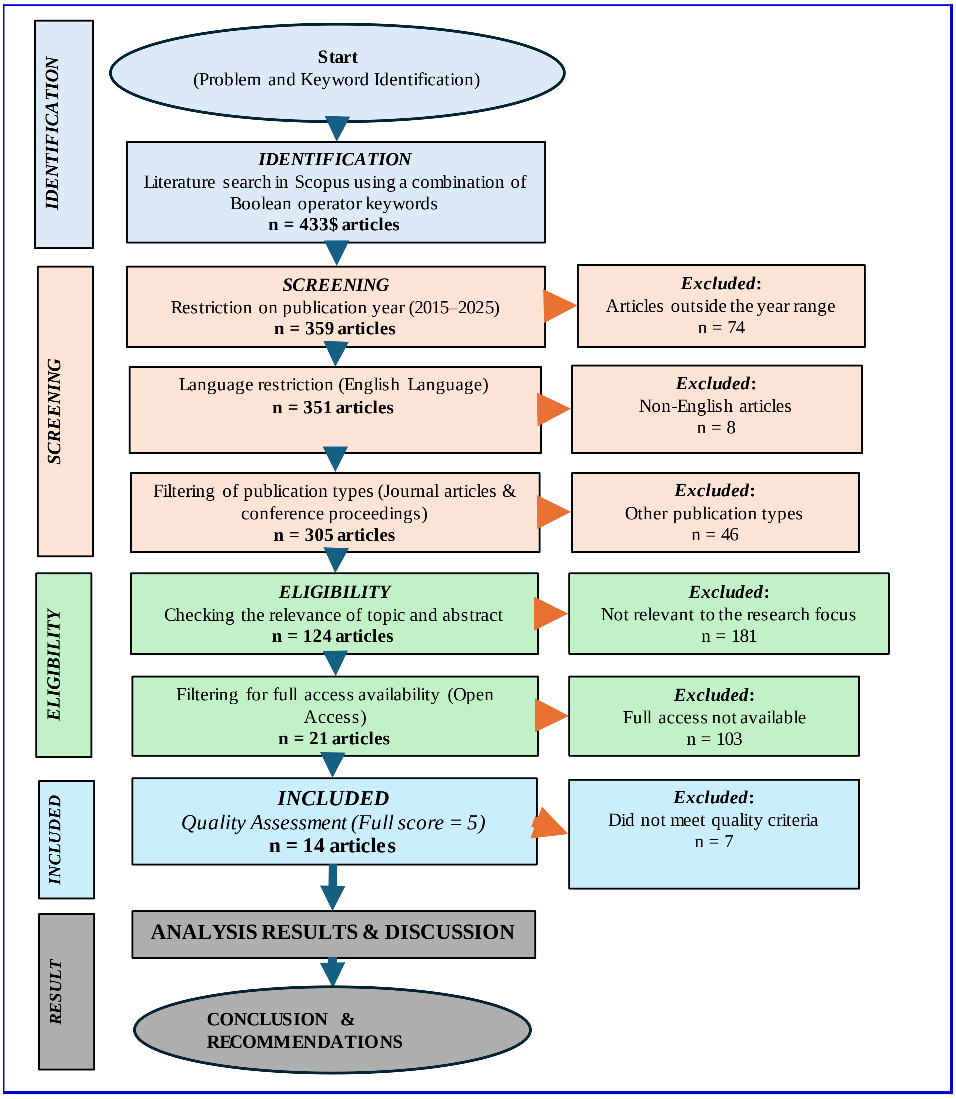

Figure 1. PRISMA flow diagram.

Table 3. Inclusion and exclusion criteria.

Criteria	Inclusion	Exclusion
Type of Publication	Peer-reviewed journal articles, conference proceedings	Non-academic articles, blogs, opinion papers, editorials
Publication Year	2015–2025	Before 2015
Language	English (and, if relevant, Indonesian)	Languages other than English or Indonesian
Topic	Application of LC in construction focusing on efficiency and sustainability	Studies unrelated to construction, LC, or efficiency/sustainability
Approach	Practical implementation, strategies for efficiency, or integration of LC with technology/management tools	Purely theoretical without application to construction projects
Relevance	Contribution of LC to cost, time efficiency, and sustainable infrastructure	Studies focusing only on other aspects (e.g., safety) without relation to LC or sustainability

To ensure methodological rigor, each shortlisted study was subjected to a quality assessment. The evaluation followed a checklist adapted from CASP, JBI, and Kitchenham et al., comprising five questions that examined: (1) the clarity of LC application; (2) the description of lean principles or tools; (3) the identification of efficiency benefits; (4) the discussion of sustainability contributions; and (5) the reliability of the research methodology. Each criterion was scored as Yes (1), Partial (0.5), or No (0). The quality assessment criteria are summarized in Table 4.

Table 4. Quality assessment questions.

No.	Question
Q1	Does the study explicitly discuss the application of Lean Construction in the construction industry?
Q2	Does it describe lean concepts, principles, or tools (e.g., LPS, VSM, JIT)?
Q3	Does it highlight the efficiency benefits in terms of cost, time, or quality?
Q4	Does it address LC's contribution to sustainable infrastructure (economic, social, environmental)?
Q5	Is the research methodology clearly described and reliable (e.g., case study, survey, experiment, or systematic review)?

Only studies that met the inclusion criteria and achieved satisfactory quality scores were selected for synthesis. During the data extraction phase, a coding matrix was developed to systematically capture key information, including the study title, author(s), publication year, research method, main findings on LC application, efficiency and sustainability contributions, and identified limitations. The final stage was the reporting phase, which involved systematically synthesizing and organizing the extracted data. The results were analyzed to identify dominant themes, research methods, and existing gaps in the literature. The findings are presented in the next section, structured to highlight LC's role as an efficiency strategy for sustainable infrastructure, its integration with digital technologies, and its implications for developing countries.

3. Results and Discussion

3.1. Data search results.

From the initial total of 433 publications retrieved from the Scopus database, only 14 articles were retained after a rigorous screening process following the PRISMA guidelines and quality assessment. Scopus was selected as the primary database because of its broad international coverage, rigorous verification system, and indexing of high-impact journals, which together ensured the validity and credibility of the included sources [26]. The filtering process was designed to ensure that only studies directly relevant to Lean Construction, explicitly describing its applications, and meeting methodological standards with a total quality score of 5 were included. The final set of 14 articles was considered scientifically adequate, as recommended by Kitchenham and Charters [17], since it represented the highest-quality literature necessary to address the research objectives. The details of these articles are presented in Table 5.

Table 5. Selected articles for analysis.

No	Title	Author/Year
1	Environmental Monitoring and Assessment for Sustainable Construction Projects: Leveraging Lean Techniques	[28]
2	Toward a Holistic View on Lean Sustainable Construction: A Literature Review	[29]
3	Lean and Green Production for the Modular Construction	[30]
4	Lean-BIM Collaborative Approach for Sustainable Construction Projects in Malaysia	[31]
5	Assessment of the Role of Lean Construction Practices in Environmental Sustainability	[32]
6	Lean and Sustainable Project Delivery in Building Construction: Development of a Conceptual Framework	[33]
7	Design Initiative Implementation Framework: A Model Integrating Kolmogorov-Smirnov in Sustainable Practices for Triple-Bottom-Line Principles in Construction Industry	[34]
8	Integrating Lean Construction with BIM and Sustainability: A Comparative Study of Challenges, Enablers, Techniques, and Benefits	[35]
9	Development of Lean Approaching Sustainability Tools (LAST) Matrix for Achieving Integrated Lean and Sustainable Construction	[36]
10	Lean Construction and Sustainability: A Review of Research Trends and Implications for the United Nations SDGs	[37]
11	Integrating Lean Construction with Sustainable Construction: Drivers, Dilemmas and Countermeasures	[38]
12	A Synergetic Effect of the Integration of Lean, Sustainable Construction Practices and Alliance Contract on Operation Performance in the Indian Construction Industry	[39]
13	Systematic Review of Lean Construction: An Approach to Sustainability and Efficiency in Construction Management	[40]
14	Evaluating the Contribution of Lean Construction to Achieving Sustainable Development Goals	[41]

The step-by-step selection process is illustrated in Figure 1, which presents the PRISMA flow diagram. From the initial 433 publications, only 14 studies successfully passed the inclusion and quality assessment criteria and were thus included in the analysis [28].

3.2.Analysis of the 14 selected articles.

The analysis of the 14 selected articles was organized into seven categories to ensure a comprehensive understanding of the research landscape: (1) publication trends, (2) geographical distribution, (3) research methods, (4) main thematic areas, (5) sustainability dimensions, (6) key contributions, and (7) level of technology integration. This structure facilitated the identification of dominant topics and research gaps.
The temporal and geographical distribution indicated that Asia and Europe dominated the studies (28.57% each), followed by the Middle East, the Americas, Africa, and Australia. Research activity peaked in 2024, showing broader geographical coverage. These patterns are illustrated in Figure 2. The thematic analysis showed that most studies (42.86%) examined Lean Construction in relation to sustainability, with the LC–BIM–Sustainability subtheme representing 21.43%. Environmental monitoring and project performance/efficiency each accounted for 14.29%, while green production/modular construction represented 7.14%. The thematic distribution is presented in Figure 3.

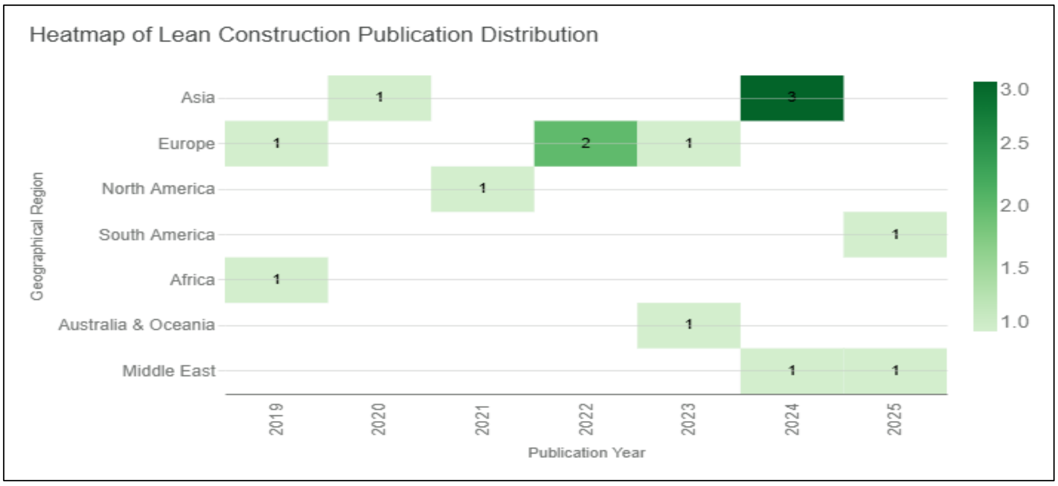

Figure 2. Heatmap of publication trends.

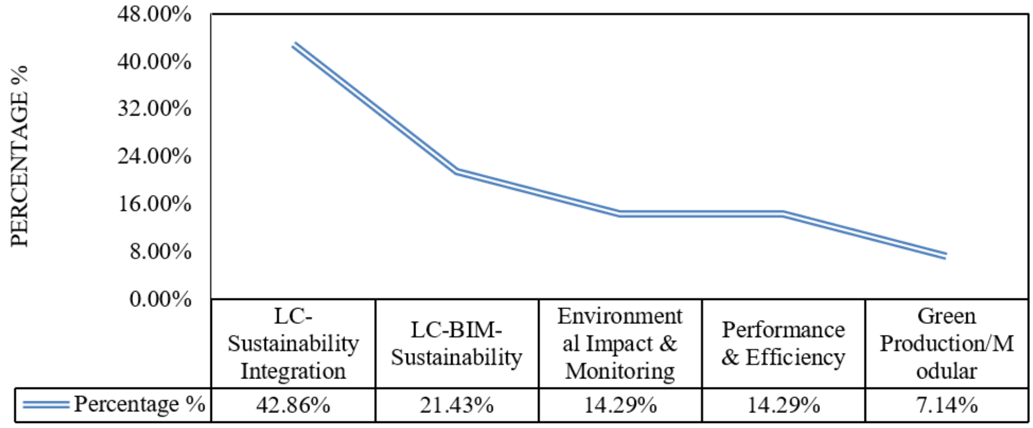

Figure 3. Distribution of main themes.

Most reviewed studies emphasized environmental and economic sustainability: 35.71% targeted waste reduction and resource efficiency; 28.57% focused on cost and time efficiency. Only 14.29% addressed social sustainability (worker safety, well-being, organizational culture), indicating an imbalance that favors technical/economic issues over social aspects (Figure 4).

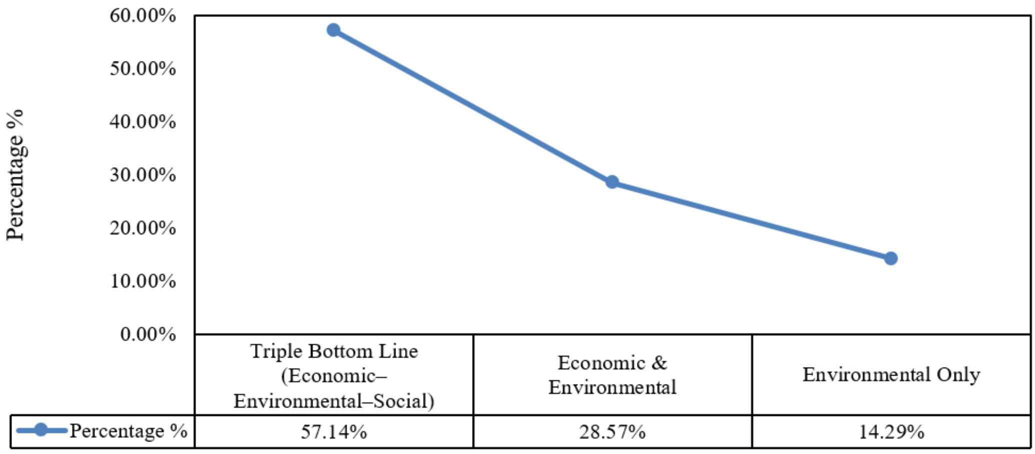

Figure 4. Sustainability dimensions.

Among the selected studies, the Systematic Literature Review (SLR) was the most common approach, accounting for 42.86%. Surveys and questionnaires represented 21.43%, while case studies and mixed methods each accounted for 14.29%. Traditional literature reviews (non-SLR) were the least used at 7.14%. These findings suggested that research on Lean Construction and sustainability remained dominated by synthesis-based studies rather than empirical validation, although some methodological diversity was evident. The proportions of research methods are illustrated in Figure 5. Regarding contributions, most studies proposed conceptual frameworks or models (35.71%). Empirical evidence accounted for 28.57%, integration analyses for 21.43%, and tool or matrix development for 14.29%. This indicated that the field remained largely conceptual, with limited practical tools available for industry implementation. The distribution of contributions is presented in Figure 6. Level of technology integration varied: 50% used traditional lean methods; 21.43% explored LC–BIM integration; 14.29% examined advanced analytics; and 14.29% considered monitoring systems (Figure 7). This distribution indicates an early but uneven uptake of digital tools in LC research.

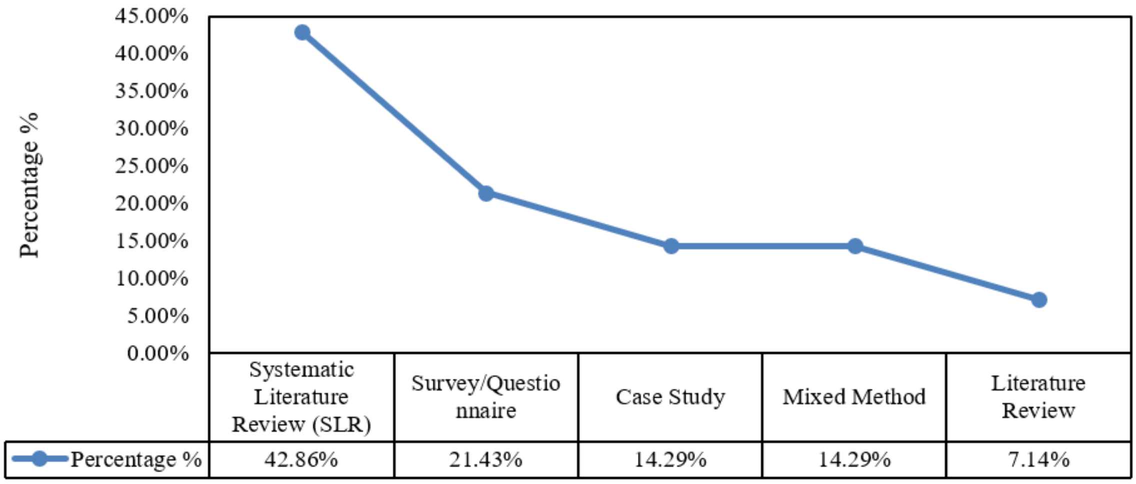

Figure 5. Research methods.

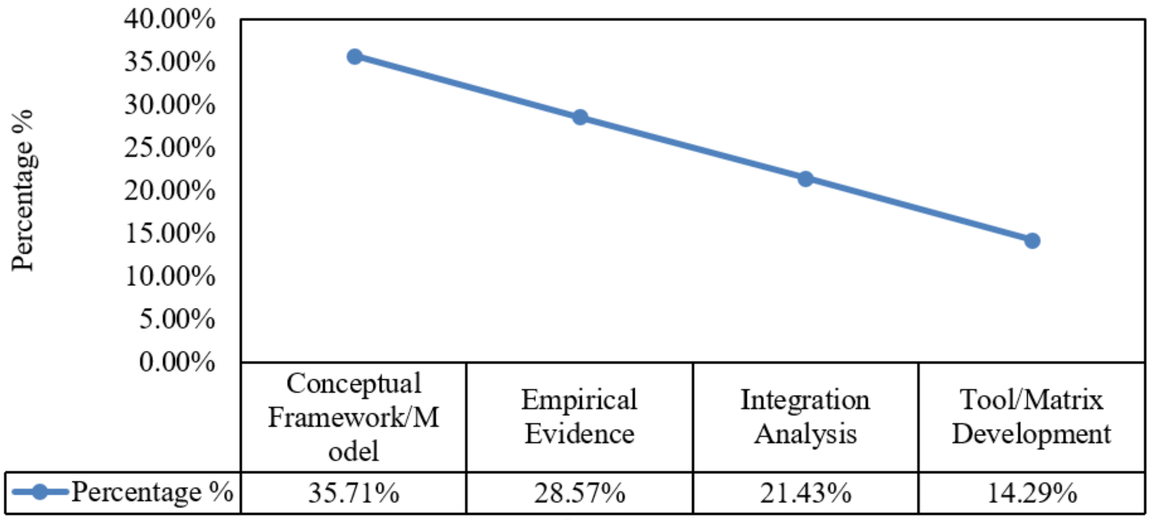

Figure 6. Key Contributions of the selected studies.

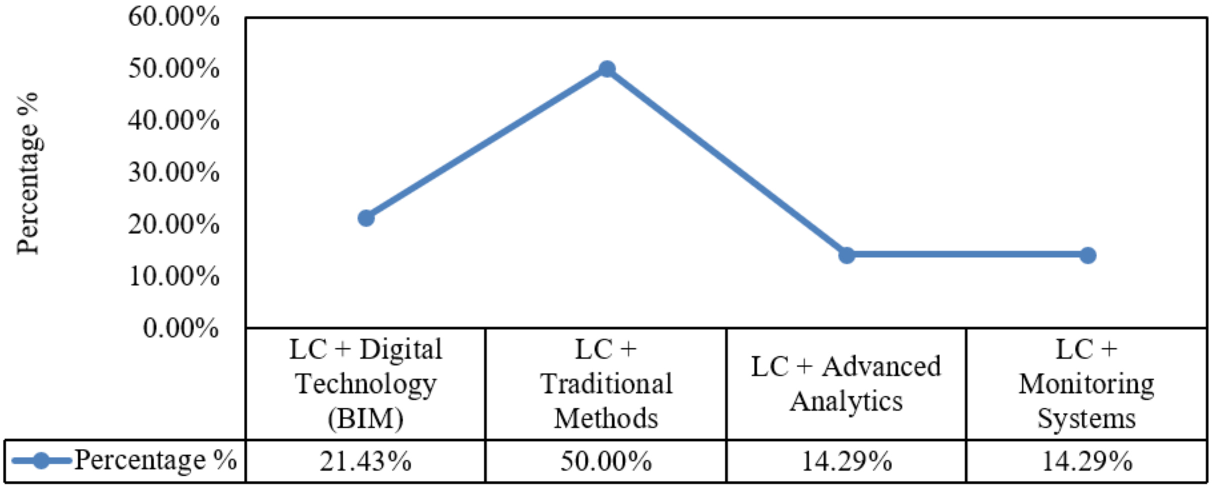

Figure 7. Level of technology integration.

3.3. Differences in lean construction implementation between developed and developing countries.

The comparison of Lean Construction adoption between developed and developing countries revealed distinct contrasts. As illustrated in Figure 8, developed countries benefited from strong regulatory frameworks, advanced technologies such as BIM, IoT, and digital twins, and organizational cultures that supported innovation. In contrast, in developing countries such as Indonesia, LC implementation remained largely confined to project management aspects (cost, time, quality), with digital integration still underdeveloped. Barriers included limited human resources, lack of comprehensive BIM policies, and weak industry awareness.

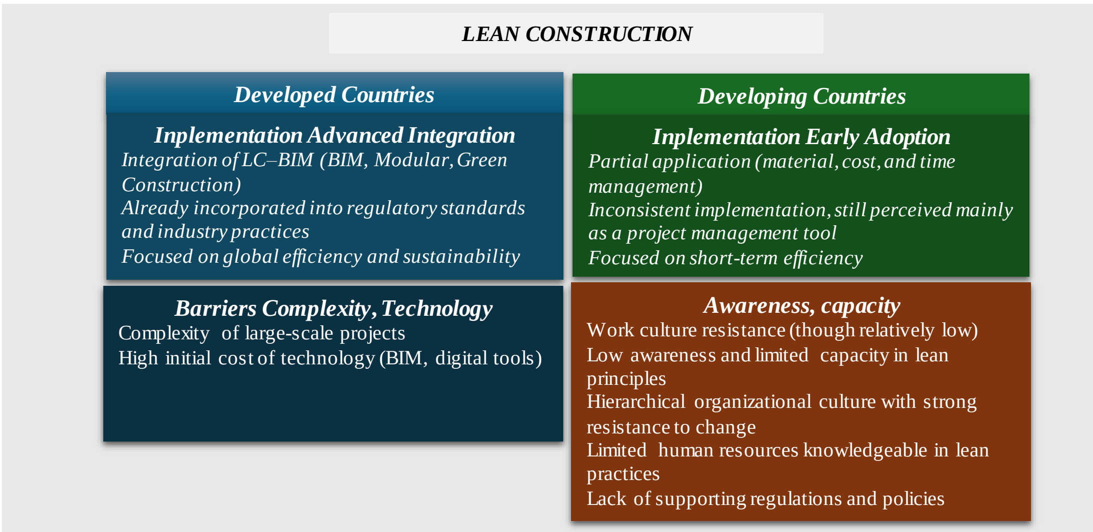

Figure 8. Differences in LC implementation and barriers between developed and developing countries.

3.3.1. Social dimension underexplored.

Although several articles demonstrated LC's capacity to improve efficiency and environmental outcomes, there was a notable scarcity of rigorous empirical studies examining social impacts, such as labor welfare, inclusive decision-making, and job quality. Where social aspects were mentioned, they were frequently descriptive or conceptual rather than measured using empirical indicators such as safety incidence rates, worker satisfaction indices, or equity metrics. This gap suggested that current LC implementations risked optimizing for short-term efficiencies while overlooking longer-term social sustainability and workforce resilience.

3.3.2. LC–BIM–CE integration remained conceptual in developing contexts.

While LC–BIM synergies were often proposed as enablers of Circular Economy (CE) practices, including material traceability and design for disassembly, most studies remained theoretical or limited to pilot simulations. Few provided field-level validation in the Global South. Constraints such as fragmented supply chains, informal labor practices, and limited digital infrastructure hindered practical implementation and limited the transferability of results from developed-country case studies.

3.3.3. Implementation trade-offs and unintended consequences.

The literature rarely examined trade-offs that arose when prioritizing LC efficiency goals, such as just-in-time deliveries, in contexts with weak supply chains or informal labor markets. Potential unintended outcomes, including increased workload pressure, informal subcontracting pressures, or erosion of local labor protections, were not systematically investigated. This oversight indicated the need for mixed-method and longitudinal field studies to capture socio-organizational effects alongside technical performance.

3.4.Conceptual framework of lean construction – technology – sustainability.

To address the research objectives, this study developed a conceptual framework illustrating the logical relationships between input factors, lean mechanisms, project efficiency, and sustainability outcomes. The framework emphasized how Lean Construction practices, when combined with digital technologies such as BIM and IoT, could enhance efficiency while advancing sustainability goals. The proposed model is shown in Figure 9. The framework comprised four main components. First, input factors included Lean practices (LPS, VSM, JIT, continuous improvement), digital technologies (BIM, IoT, digital twins), and barriers such as human resource limitations and organizational resistance. Second, lean mechanisms encompassed waste reduction, cost efficiency, time efficiency, and collaboration/transparency. Third, the outputs reflected project efficiency in terms of cost, time, quality, and reliability. Finally, these outputs contributed to sustainability dimensions, encompassing economic, environmental, and social outcomes. The proposed framework provided both theoretical and practical implications. Theoretically, it expanded understanding of Lean Construction as a managerial strategy integrated with digital transformation to achieve sustainability. Practically, it served as a guide for contractors, consultants, and policymakers in implementing context-specific Lean strategies while accounting for organizational readiness and local barriers. Furthermore, the model highlighted opportunities for future research, particularly empirical validation in developing countries where structural challenges remained significant.

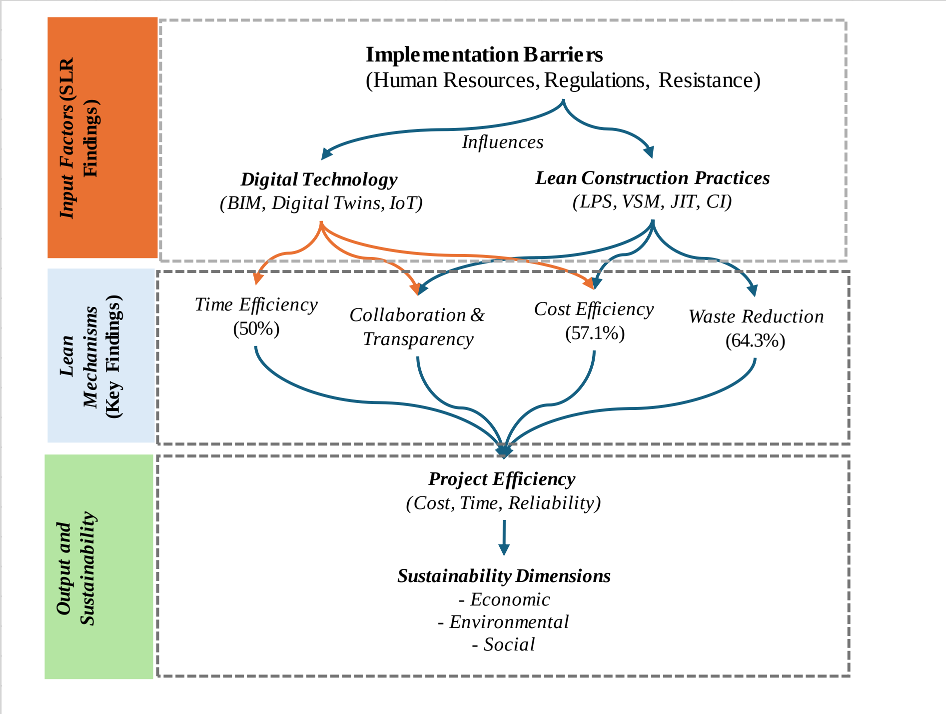

Figure 9. Conceptual framework: lean construction – technology – sustainability.

3.4.1. Practical implications for developing countries.

The framework highlights that effective LC–BIM–CE adoption in developing countries requires simultaneous investment in (a) human capital (training, capacity building), (b) regulatory incentives and standards that encourage CE practices, and (c) incremental digital adoption strategies (hybrid workflows that combine low-tech and digital tools). Without these enabling conditions, LC–BIM integration risks remaining pilot-level or reinforcing existing inequalities (e.g., favoring large contractors who can afford technology).

3.4.2. Research implications.

There is a pressing need for empirical studies that (1) operationalize social sustainability metrics in LC research, (2) pilot LC–BIM–CE interventions in real projects within developing contexts, and (3) evaluate socio-technical barriers through mixed-method designs. Longitudinal and participatory action research would be particularly valuable to observe adoption dynamics, institutional change, and distributional impacts over time.

3.4.3. Policy implications.

Policymakers should consider targeted incentives (tax breaks, procurement preferences, technical assistance) to encourage small and medium contractors to adopt LC–BIM practices aligned with CE. Standards and certification schemes may help formalize best practices while protecting workers' welfare during transitions to lean/digital processes.

4. Conclusions

The analysis of the 14 selected articles confirmed that Lean Construction (LC) played a strategic role in enhancing project efficiency while supporting sustainable infrastructure development. The literature showed that LC contributed substantially to waste reduction (64.3%), cost efficiency (57.1%), and time efficiency (50%), collectively reinforcing the economic, environmental, and social dimensions of sustainability. Furthermore, the integration of LC with digital technologies such as Building Information Modelling (BIM), digital twins, and Circular Economy (CE) principles emerged as a prominent theme, although practical implementation remained relatively limited. The potential of CE integration—particularly in material reuse, recycling, and design for disassembly—required further exploration to strengthen sustainable resource management and long-term efficiency. Despite these contributions, several critical research gaps were identified. First, most studies remained conceptual and primarily relied on systematic literature reviews, highlighting a scarcity of project-based empirical validation, especially in developing country contexts. Second, the integration of LC with advanced digital technologies had not been systematically tested, leaving practical benefits largely unvalidated. Third, the social dimension of sustainability, including workplace safety, labor welfare, and organizational culture, remained underexplored, even though these factors are crucial for holistic sustainability in construction practices. To address these gaps and guide future research and practice, several recommendations were proposed. Empirical studies based on real projects and case investigations should be intensified to validate LC's contributions to efficiency and sustainability, particularly in developing countries with structural challenges differing from those in developed nations. The integration of LC with advanced digital technologies such as BIM, the Internet of Things (IoT), artificial intelligence, and digital twins should be expanded to fully leverage systematic efficiency gains. In parallel, greater attention must be directed toward the social dimension of sustainability—including worker safety, organizational culture, and labor well-being—which remains underrepresented in the literature. Additionally, the development of practical tools, implementation matrices, and applicable frameworks is essential to move LC beyond theoretical discourse and enable effective industry adoption. Finally, government regulations and policy support should be strengthened through incentives and standardized guidelines to accelerate LC adoption and facilitate the transition toward sustainable construction practices. This study not only synthesized the role of LC as an efficiency strategy for sustainable infrastructure but also provided actionable recommendations to enhance empirical validation, technological integration, and contextual adoption. Strengthening these aspects will ensure that Lean Construction evolves into a more practical, comprehensive, and sustainability-oriented approach, capable of addressing challenges in construction industries across both developed and developing countries.

Competing Interest

All authors should disclose any financial, personal, or professional relationships that might influence or appear to influence their research.

Author Contributions

Firmino Fitrino Ximenes and Nectaria Putri Pramesti contributed equally to the study. Both authors were involved in conceptualization, methodology, data collection, formal analysis, visualization, manuscript preparation, and final approval of the submitted version.

Data Availability Statement

All data used in this study are available upon reasonable request from the corresponding author.

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