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Identifying Barriers to Lean–Intelligent Construction in the Project Phase: A Review

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ABSTRACT

The integration of Lean Construction principles and Intelligent Construction Technologies (ICT) offers transformative potential for enhancing efficiency, minimizing waste, and improving decision-making throughout the construction life cycle. However, adoption remains constrained by complex technical, financial, environmental, and social barriers. This study conducts a Systematic Literature Review (SLR) using the PRISMA protocol to identify and classify key barriers hindering Lean–Intelligent Construction implementation. Twenty-eight peer-reviewed articles published between 2021 and 2025 were analyzed, with barriers mapped across project phases and lean waste categories. The findings reveal that technical and social barriers are the most dominant, particularly during the design and construction phases, leading to critical waste types such as waiting, defects, and over-processing. Financial and environmental barriers show more localized effects, primarily linked to inventory and motion waste during procurement and construction. The Sankey diagram visualization demonstrates that waste generation in intelligent construction is not isolated but emerges from the interaction of multiple barriers across project stages. This study contributes to a deeper understanding of how digital and organizational inefficiencies propagate lean waste, providing a foundation for targeted interventions in different project phases. The findings emphasize the need for holistic strategies that combine technological innovation, organizational change management, and policy reform to achieve sustainable digital transformation in the construction sector.

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1. INTRODUCTION

The adoption of Intelligent Construction Technologies (ICT) still faces significant obstacles, despite its great potential to improve efficiency, reduce costs, and accelerate project timelines. Traditional construction projects, which often rely on manual methods and fragmented processes, face major challenges in transitioning to more integrated, technology-based methods. One of the main obstacles hindering technology adoption is the limited availability of adequate human resources and infrastructure. In many countries, especially in developing regions, only 16.9% of large industrial companies use artificial intelligence (AI), with most companies facing major constraints related to costs and inadequate infrastructure. This shows that although smart technologies such as Building Information Modelling (BIM) and the Internet of Things (IoT), offer great benefits in project efficiency, limited access to these technologies restricts their widespread adoption. In Brazil, around 54.6% of companies report that a lack of skilled labor is a major challenge in implementing these new technologies (Li et al., 2021). According to research in Mexico, approximately 20% of companies in the small and medium-sized construction sector feel that their understanding of these technologies is limited, which causes fear of replacing long-established methods (Romo, 2024).

A lack of understanding and awareness of the potential of smart technologies is also a significant barrier. Most workers in the construction industry still prefer to use proven traditional methods and may face difficulties in adapting to new technologies. These obstacles hinder the full implementation of smart technology, which, in turn hinders efficiency improvements and waste reduction in construction projects. In addition to these challenges, the construction industry also faces issues related to construction waste and inefficiency. Uncontrolled use of resources in construction often leads to negative environmental impacts, including material waste, carbon emissions, and high construction waste (Raza, 2024). The construction sector's impact is evident in its contribution to 40% of global solid waste generation, 40% of total energy consumption, and 16% of worldwide water usage (Raza, 2024b). Without effective technology adoption, the potential of these technologies cannot be maximized, thereby limiting the achievement of key lean construction objectives, such as reducing time and costs and reducing resource waste. Therefore, a better approach is needed in terms of training, change management, and effective communication to facilitate this transition (Olukanni et al., 2025).

In many countries, limited access to technology and funding are major barriers to the implementation of smart technologies. According to a study by Deloitte, approximately 48% of construction companies in the Asia-Pacific region reported that the cost of training and skills development was the greatest challenge in adopting digital technology, while 45% said that higher operating costs due to the use of diverse data environments prevented them from investing in new technology (Deloitte, 2021). This shows that despite awareness of the benefits of technology, many companies are unable to meet the initial investment costs required to adopt smart technology. This study introduces a multidimensional classification framework based on two critical contexts: (1) construction waste categories and (2) project life cycle phases. This classification not only enables a more contextualized understanding of the barriers but also facilitates more targeted recommendations for overcoming these obstacles in different project phase conditions.

2. RESEARCH OBJECTIVES

This study aims to conduct a systematic literature review (SLR) and analysis of the barriers to Lean–Intelligent Construction adoption in the construction project phase. The objectives are to: (1) Identify the main barriers hindering the adoption of lean and Intelligent Construction Technologies in the construction project phase. (2) Analyze the impact of these barriers on the efficiency, waste reduction, and overall

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performance of construction projects. (3) Propose future research direction to overcome these barriers and enhance the effective adoption of Lean–Intelligent technologies in the construction industry.

This paper aims to assist scholars and practitioners in understanding the challenges faced during the adoption of Lean and Intelligent Construction and to highlight potential solutions for improving project outcomes.

3. CONCEPTUAL BACKGROUND

The implementation of smart construction is an effort to transform the construction industry through the integration of technologies such as BIM, IoT, AI, and digital twins to improve efficiency, reduce waste, and support real-time data-driven decision-making. However, its implementation is still hampered by technical barriers such as a lack of interoperability and high costs, as well as socio-organisational barriers in the form of resistance to change and a shortage of skilled labour (Waqar, 2024; Moshood et al., 2024). On the other hand, lean construction offers a philosophy of eliminating waste from waiting for materials, design errors, and unnecessary worker movement through smooth workflows, team collaboration, and pull scheduling based on actual needs, thereby creating maximum value for customers with minimal resources (Li et al., 2021; McNamara & Sepasgozar, 2021). These two approaches are closely interrelated: smart construction provides the “digital tools” to realise lean principles, while lean provides the “philosophical framework” that guides the use of technology so that it does not become a new form of waste.

Concrete examples include IoT sensors that monitor material arrivals in real time to support lean just-in-time systems, 5D BIM that simulates the impact of design changes to prevent rework, and AI that predicts the risk of delays so that pull scheduling can be tightened without compromising safety (Duarte et al., 2021). This synergy has the potential to reduce project costs by 10–20% and accelerate completion times by up to 30%, but it requires a cultural shift: all parties, from project owners and contractors to field workers, must be willing to share data transparently, undergo continuous digital training, and accept the gradual transfer of authority from humans to intelligent systems. Therefore, the integration of lean and smart construction is not merely a combination of technology and management, but a holistic transformation towards a leaner, faster, and more sustainable construction industry that is ready to face the complex challenges of the industry 4.0 era.

4. RESEARCH METHOD

This study uses a Systematic Literature Review (SLR) based on PRISMA Protocol (Fig.1) to identify barriers to the adoption of lean–intelligent construction during the construction project phase. Articles were sourced from Scopus and Web of Science using the search string “Barriers” AND “intelligent construction” AND “lean construction” AND “waste”, limited to peer-reviewed journal publications in English between 2021 and 2025. The initial search produced 129 documents, which were then screened through duplication removal, title and abstract review, and full-text assessment, resulting in 28 relevant articles.

The selection focused on studies discussing barriers or challenges in implementing intelligent construction technologies linked to lean construction or waste reduction within planning, execution, or post-construction phases. Articles that were conceptual only, not peer-reviewed, non-English, or unrelated to project implementation were excluded. The selected data were then analyzed to map keyword relationships, visualize publication distribution by year and journal, illustrate country–keyword connections using a Sankey diagram, and display development degree versus relevance degree to identify research positioning. Qualitative content analysis was conducted to extract and categorize barriers, which were then organized based on lean waste types such as time, cost, defects, waiting, overprocessing, and resource inefficiency, as well as the construction project phase in which they occur. This integrated approach provides a clear and

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structured understanding of dominant barriers, their waste implications, and their positioning across the construction life cycle.

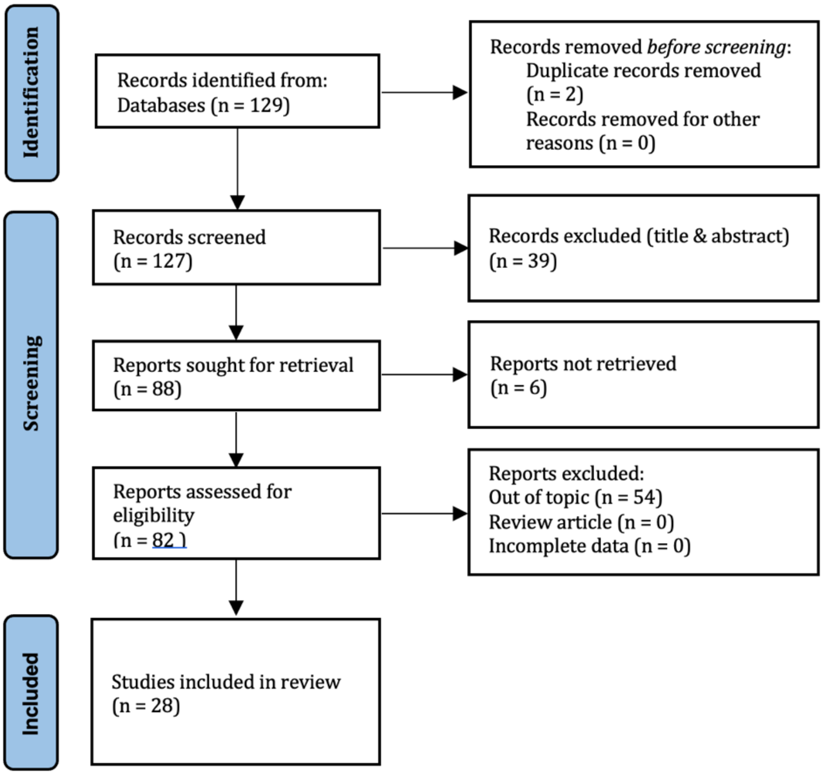

Fig. 1. Research Methodology Framework using PRISMA

5. RESULT

5.1 Journal Source Analysis

Fig. 2 shows the main trends in construction research, with a strong focus on digital transformation, sustainability, and automation. Buildings is the leader in this field, with a significant number of publications, indicating its dominance as a research platform for construction processes. Engineering, Construction, and Architectural Management, along with Construction Innovation, reflect an increased emphasis on management and innovation aspects of construction, particularly related to Lean practices and technology integration. Sustainability is gaining attention, as evidenced by the journals Applied Sciences and Smart and Sustainable Built Environment, signalling a growing interest in environmentally friendly technologies and greener building methods. Automation in Construction highlights the role of new technologies such as AI and IoT, which are driving greater efficiency and automation in the industry. Finally, specialised journals on engineering construction and building engineering emphasise the continued importance of traditional engineering practices, ensuring structural integrity while adopting technological advances. These changes point to a shift towards smarter, more sustainable and efficient construction practices.

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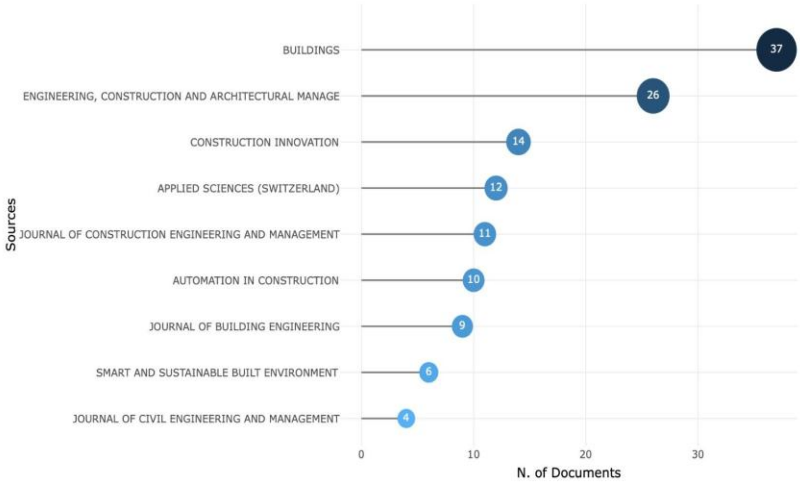

Fig. 2. Prolific Journals in Construction Research by Document Count

5.2 Active Countries Analysis

Fig.3 shows the relationship between three main categories in construction research: topics, countries, and combined keywords, providing an in-depth overview of global research trends in the construction sector. The dominant topics include construction, sustainability, digital, lean, and approaches. These topics illustrate a shift in focus within the construction industry towards the application of lean construction principles, digitalization, and sustainability practices. Sustainability, in particular, is gaining increasing attention, reflected in the rising frequency of keywords such as sustainable construction and sustainable development, which signify the importance of meeting development needs without harming the environment. At the country level, China stands out as a major leader in construction research publications, with significant contributions in the fields of project management, BIM (Building Information Modelling), and sustainability. This reflects China's dominance in adopting smart construction technologies and its need to achieve a more efficient construction industry in the coming decades.

The United Kingdom, Australia, and India also emerge as major contributors to research on sustainability and BIM, demonstrating international collaboration in developing more efficient and environmentally friendly construction solutions. These countries are also actively utilizing technology to optimize construction processes and project management, reflecting global trends in the adoption of digitalization and automation. The most frequent keywords, such as lean construction, BIM, sustainable construction, and life cycle, indicate that global research is increasingly focused on the application of digital technologies to improve efficiency and reduce waste in construction projects. In addition, the use of the keywords decision making and architectural design emphasizes the importance of technology-supported decision-making in project planning and implementation.

This illustrates how technologies such as BIM and IoT, play a vital role in providing accurate, real-time information to support better decisions throughout the construction project life cycle. Overall, this network analysis shows a major shift in the construction industry towards the implementation of smart technologies, lean construction, and sustainability practices. Countries such as China, the United Kingdom, and Australia dominate research in these topics, reflecting the importance of international collaboration to address global challenges in achieving efficiency and sustainability in construction. This research also highlights how technology can overcome traditional barriers in construction and drive the transition towards more efficient and environmentally friendly practices.

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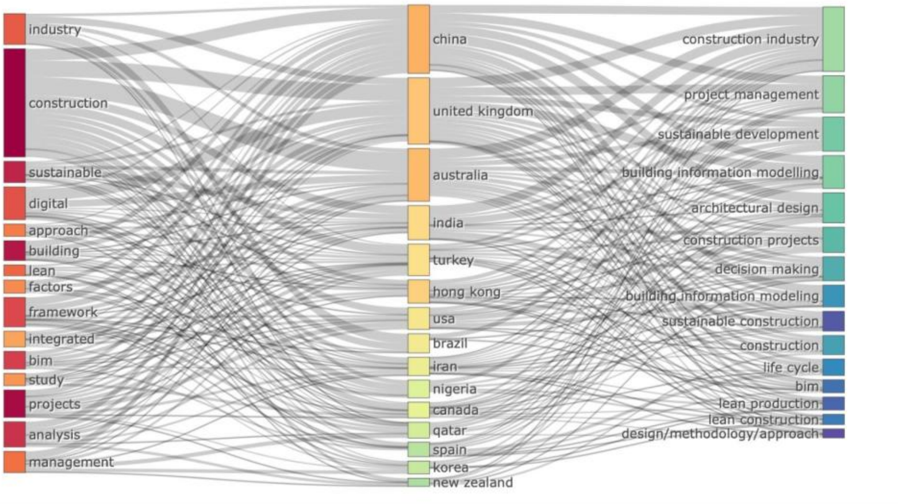

Fig. 3. Mapping active countries in research

5.3 Barrier Mapping for Lean–Digital Integration Across Construction Phases

Mapping of obstacles was carried out to identify various constraints that arise in the integration of digital transformation and lean construction principles in construction projects. Through a synthesis of literature from various previous studies, obstacles were classified into four main categories, namely technical, financial, environmental, and social. Each category represents a different source of problems but are interrelated in influencing the effectiveness of automation and construction project efficiency. Technical barriers are generally related to technological limitations and system complexity that hinder efficiency. Financial barriers are dominated by high initial costs and fragmented procurement processes. Meanwhile, environmental obstacles arise due to uncertain project location conditions, poor supply chains, and suboptimal material flow planning. Social obstacles include resistance to change, workforce skill gaps, and weak cross-team collaboration.

To understand the relationship among these obstacles, project phase, and lean waste types, a mapping was carried out as presented in Table 1. This table shows how each obstacle affects the project stages (planning, design, construction, operation, and handover) and the type of waste it causes. Through this mapping, critical areas requiring strategic intervention can be identified to ensure that the integration of lean–digital can run effectively and sustainably.

Table 1. Barriers Mapping

Type of Barrier	Representative Barrier Description	Project Phase	Type of Waste	Source
Technical	Lack of interoperability and inconsistent BIM standards among systems and stakeholders	Design, Construction, Operation	Defects, Waiting, Over-processing	Duarte et al. (2021); Bühler et al. (2023); Jiang et al. (2024)
	Poor integration between BIM, ERP, and FM systems	Construction, Operation	Waiting, Over-processing	Olaseni (2022); Wang et al. (2025a); Rodrigues et al. (2022)
	Limited accuracy, performance, and compatibility of on-site sensors and IoT devices	Construction, Operation	Defects, Waiting, Motion	Duarte et al. (2021); Piras et al. (2024)

Type of Barrier	Representative Barrier Description	Project Phase	Type of Waste	Source
	Lack of standardized integration of safety and data systems in digital workflows	Construction	Defects, Over Processing	Rodrigues et al. (2022); He & Liu (2022)
	Complex or non-intuitive interfaces and excessive system complexity	Design, Construction	Motion, Over Processing	Liu et al. (2025); Piras et al. (2024)
	Late design freeze and mismatch between modules in off-site construction	Design, Construction	Waiting, Defects	Elghaish et al. (2025); Wang et al. (2025b)
Financial	High upfront cost of BIM, IoT, and robotic technologies	Pre-construction, Procurement	Overproduction, Inventory	Olaseni (2022); Rocha et al. (2025)
	Vendor lock-in and proprietary formats increase operational costs	Design, Operation	Defects, Inventory	Bühler et al. (2023)
	Costly and delayed procurement processes due to fragmented supply chain	Procurement, Construction	Waiting, Inventory	Liu et al. (2025); Garces (2025)
	High cost of technical maintenance and digital updates	All phases	Waiting, Overproduction	Patching et al. (2023); Jiang et al. (2024)
Environmental	Unpredictable sites and external conditions affect digital tool reliability	Construction, Planning	Waiting, Defects	Garces (2025); Castañeda et al. (2025)
	Poor planning of material and traffic logistics	Construction	Motion, Inventory	Wang et al. (2025a); Castañeda et al. (2025)
	Resistance to change and cultural barriers in technology adoption	Construction, All Phases	Waiting, Non-utilized Talent, Motion	Khan et al. (2023); Torres et al. (2024); He & Liu (2022)
Social	Insufficient training, skill gaps, and ageing workforce	Planning, Construction	Non-utilized Talent	Elghaish et al. (2025); Torres et al. (2024)
	Fragmented collaboration and data silos across teams	Design, Construction, Operation	Waiting, Motion, Defects	Li et al. (2021); Torres et al. (2024); Patching et al. (2023)
	Regulatory and ethical uncertainty toward AI and robotics	Design, Planning, Handover	Waiting, Over Processing	Dong et al. (2025); Jiang et al. (2024)
	Lack of strategic leadership and lean-thinking alignment	All Phases	Overproduction, All waste types	Patching et al. (2023); Jiang et al. (2024)

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5.4 Flow of Barriers and Lean Waste Across Construction Project Phase

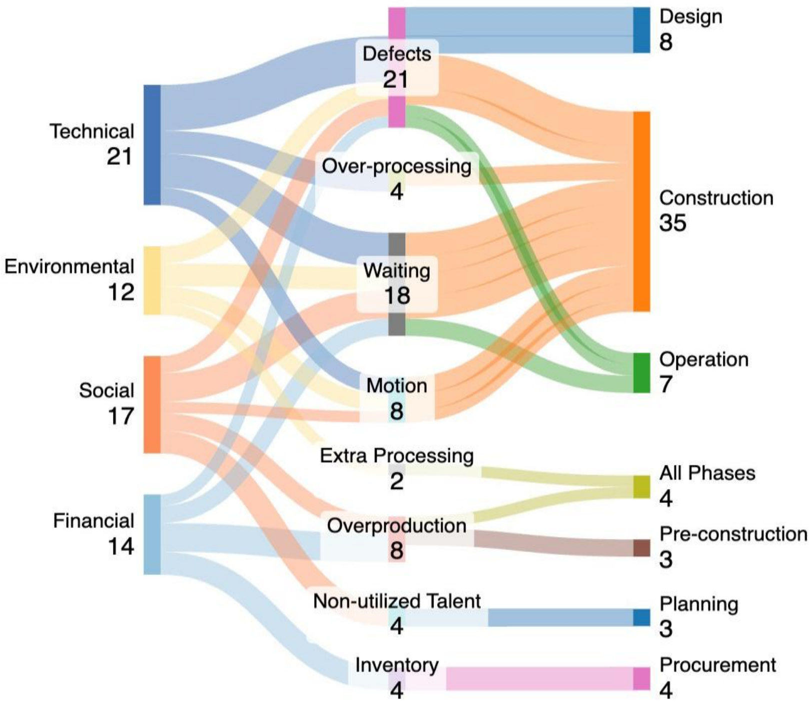

Fig. 4. Interaction Flow

The Sankey diagram illustrates the interconnection between four main types of barriers—technical, financial, environmental, and social—and their impacts on lean waste and project phases. The visualization reveals that technical and social barriers dominate, particularly in the construction and design phases. Technical barriers generate the widest range of lean waste, especially *defects*, *waiting*, and *over-processing*, due to system incompatibility and fragmented digital integration. Social barriers, meanwhile, are widely distributed across waste types—especially *waiting* and *non-utilized talent*—highlighting the influence of human and organizational resistance on digital implementation. In contrast, financial and environmental barriers show more limited but more focused effects. Financial barriers relate mainly to *inventory* and *overproduction* wastes during procurement and pre-construction, driven by high upfront costs and vendor lock-in. Environmental barriers appear mostly in the construction phase, linked with *waiting* and *motion* wastes caused by site uncertainty and logistics inefficiency. Overall, the diagram emphasizes that waste in intelligent construction arises from interconnected barriers across multiple phases, with the construction phase showing the highest concentration of waste generation.

6. DISCUSSION

In planning, external uncertainties such as weather, permits, and site conditions drive rescheduling of schedules, equipment, and existing resources. This increases waiting times. On the other hand, when acceleration is used to recover delays, it often triggers defects in work that do not receive sufficient quality monitoring. At the same time, regulatory ambiguity and data privacy prolong the approval cycle related to

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ownership, access, and retention of designs, which can add paperwork and verification that does not add value, or what we call extra processing. The digital competency gap in the planning team also means that data-based design options are less explored, so that missed improvement opportunities can lead to waste in the form of non-utilized talent, which then trickles down to the downstream phase as less constructible design decisions. In the design phase, the basics of waste management are established, so it is very important for architects and engineers to integrate strategies that minimize waste generation from the outset. Research shows that early supplier involvement is critical to achieving waste reduction goals (Othman & El-Saeidy, 2024).

Analytical studies focusing on this phase highlight several factors that influence construction waste generation, showing that proper planning during the project can significantly reduce waste (Saad, Othman, & Alamoudy, 2022). During the design phase, incompatible or non-standard digital ecosystems necessitate format conversion and manual cross-platform checking, which prolongs information lead time and adds steps without added value (over-processing). Lossy data transfer increases model/document inconsistencies and triggers rework (defects). The complexity of interfaces and tools (a steep learning curve) encourages application switching, additional support requests, and long adaptation times—resulting in motion and extra processing. In modular/off-site projects, late design freezes and imprecise inter-module interfaces force re-detailing close to production, lengthening the approval chain (waiting) while increasing the risk of defects.

In procurement, technology investments (servers, sensors, and robotics) that are not yet fully utilized can tie up capital in idle capacity, leading to overproduction (capacity exceeding demand) and inventory (idle assets). Supply chain fragmentation and mis-timed delivery create material accumulation and double handling and filed waiting, while inventory puts pressure on space and coordination. Building Information Modelling (BIM) has emerged as a lean management tool at this stage, encouraging collaborative practices that improve data sharing and decision-making (Eldeep, Farag, & Abd El-hafez, 2022). The integration of BIM with system dynamics modelling further enhances the ability of project stakeholders to visualize and simulate waste scenarios, ultimately minimizing the likelihood and impact of order changes, which are known to cause excess waste (Porwal et al., 2023).

As BIM evolves, its compatibility with emerging technologies such as blockchain is increasingly recognized as a key factor in facilitating efficient waste management and information flow throughout the construction life cycle (Celik, Petri, & Rezgui, 2023). The construction phase represents the practical implementation of design principles and is often a critical period in waste generation. Several factors contribute to waste during construction, such as inefficiencies due to poor communication between stakeholders and logistical challenges (Datta et al., 2024). Recent studies highlight the importance of adopting lean construction practices to simplify processes, thereby reducing waste (Garcés & Peña, 2023). Data re-entry and interrupted workflows slow down lookahead and decision-making, increasing waiting and over-processing. Low sensor reliability (errors, drop-outs) triggers incorrect condition assessments and manual hold point verification, resulting in defects, waiting, and motion as teams go back and forth to check inspection points.

Manual safety and quality inputs, without integration into the common data environment (CDE), increase duplicate entries and the risk of typos (extra processing, defects). For example, a comprehensive review highlights the usefulness of lean principles in optimizing construction project management, emphasizing methodologies that can minimize excessive use of materials and optimize working time (Bayhan et al., 2023). Furthermore, the introduction of prefabrication techniques shows promise in reducing waste at this stage. Prefabricated elements can significantly reduce on-site waste by ensuring components are produced to the correct specifications (Yuan et al., 2022). As the construction industry continues to adopt these modern techniques, it is important to monitor their impact on waste generation using established metrics. Across phases, a recurring pattern emerges when technology is applied without core process

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improvements, resulting in 'automation of waste' or digital overproduction: excessive data collection, duplication of work, and ultimately all types of lean waste may appear simultaneously. Weak communication chains prolong feedback loops across all phases, causing waiting and defects to accumulate and reinforcing initial barriers (Patching et al., 2023; Jiang et al., 2024; Li et al., 2021; Torres et al., 2024).

Furthermore, the application of artificial intelligence (AI) and machine learning technologies in construction has the potential to increase project efficiency, predict waste generation trends, and support more effective planning (Datta et al., 2024). As the industry evolves, it is crucial to explore the application of these technologies to drive innovation in waste management. Intervention strategies that transcend organizational boundaries, such as the adoption of collaborative structures between construction teams, strategies that integrate sustainability goals, and the ongoing involvement of stakeholders, remain key to achieving waste management efficiency (Gómez et al., 2023). Multi-criteria decision-making approaches in recent studies have highlighted the role of collaboration and innovation in aligning construction practices with sustainability goals (Romero-Perdomo & González-Curbelo, 2023). Despite the progress made, barriers to effective waste management remain, including inadequate training for workers in sustainable practices and resistance to change among traditional contractors. The need for a cultural shift in the construction industry should not be overlooked. Stakeholders must adopt a mindset that prioritizes waste reduction as a core principle in their operational strategies. The development of educational programs and workshops can increase understanding and acceptance of innovative waste management techniques, contributing to a more sustainable industry landscape.

7. CONCLUSION

This study identifies and synthesizes the critical barriers hindering the effective integration of Lean and Intelligent Construction approaches. Through a systematic literature review and barrier–waste mapping, four dominant categories—technical, financial, environmental, and social—were identified as the primary sources of inefficiency. The analysis shows that technical barriers, such as poor interoperability and fragmented digital systems, generate the highest frequency of lean waste, particularly defects and waiting. Social barriers, including resistance to change and insufficient digital skills, are found to significantly contribute to non-utilized talent and process delays across all phases. Financial barriers, represented by high upfront costs and vendor lock-in, primarily affect the procurement and pre-construction phases, while environmental barriers, such as unpredictable site conditions, intensify waste during construction.

The Sankey diagram analysis illustrates that lean waste in intelligent construction arises from a systemic chain of interdependent barriers, rather than isolated causes. The construction phase exhibited the highest waste concentration, emphasizing the urgent need for collaborative digital ecosystems, integrated data environments, and continuous workforce upskilling. Moreover, the study reinforces that implementing technology without parallel process reform risks "automating waste"—replicating inefficiencies in digital form. Overall, the findings underline the necessity of approaching Lean–Intelligent Construction not merely as a technological upgrade, but as a strategic transformation that aligns digital tools, lean thinking, and human capability. The integration of these dimensions is critical for realizing sustainable productivity and waste reduction across the project life cycle. Future studies should move beyond descriptive classification toward quantitative modeling and causal mapping of the interactions between barriers, waste types, and project phases. Integrating system dynamics, Bayesian network modeling, or Structural Equation Modeling (SEM) can provide a deeper understanding of how digital inefficiencies and social resistance collectively propagate waste across the life cycle. Moreover, cross-country comparative research—particularly in developing economies such as Indonesia, Brazil, and India—is needed to examine the contextual influence of policy, infrastructure, and cultural readiness on Lean–Intelligent Construction adoption. Empirical case

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studies from real project implementations would also help validate the conceptual framework developed in this paper, identifying context-specific mitigation strategies.

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9. CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

10. AUTHORS' CONTRIBUTIONS

Ferry Firmawan contributed to the conceptualization of the study, research design, supervision, interpretation of findings, and overall manuscript preparation. Lala Anggraini contributed to the literature search, screening of relevant articles, data extraction, and analysis of barriers related to Lean–Intelligent Construction. Diajeng Sekar Shaliha contributed to the organization of systematic literature review, PRISMA-based article selection, and preparation of the research methodology section. Hendra Masvika contributed to the classification and mapping of barriers according to project phases and lean waste categories. Agnesia Putri Kurnianingtyas contributed to the visualization of findings, interpretation of the Sankey diagram, and refinement of the discussion and conclusion sections. All authors reviewed, edited, and approved the final version of the manuscript for publication.

11. DECLARATION OF GENERATIVE AI IN THE WRITING PROCESS

The authors declare that generative artificial intelligence (AI) tools may have been used solely to support language refinement during the preparation of this manuscript. Such tools were used only to improve grammar, sentence structure, clarity, and overall readability. All aspects of the research, including the study design, data collection, data extraction, analysis, interpretation of findings, and final academic decisions, were conducted, reviewed, and approved by the authors. The authors take full responsibility for the accuracy, integrity, originality, and scholarly content of this manuscript.

12. DATA AVAILABILITY/SUPPLEMENTARY MATERIALS

The data and/or supplementary materials supporting the findings of this study are available from the corresponding author upon reasonable request, where applicable.

13. ETHICS STATEMENT

The authors declare that this study did not involve human participants or animal subjects. Where applicable, all procedures were conducted in accordance with relevant institutional guidelines, safety requirements, and ethical standards.

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