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SYSTEMATIC LITERATURE REVIEW ON THE INTEGRATION OF LEAN MANAGEMENT AND SUSTAINABLE DEVELOPMENT IN MODULAR OFF-SITE CONSTRUCTION

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ABSTRACT: Modular Off-site Construction (MOC) offers greater efficiency and cost-effectiveness compared to traditional construction methods. However, there is significant potential to further enhance sustainability outcomes by adopting Lean principles on a wider scale. With growing expectations for sustainable practices, it is essential to explore how Lean management principles recognized for reducing waste and improving efficiency can be effectively integrated into MOC to address the economic, environmental, and social dimensions of Sustainable Development (SD).There is an opportunity to optimize SD outcomes, including cost reduction, waste minimization, quality improvement, and social well-being, through the application of specific Lean tools and practices in MOC. However, adapting Lean tools within MOC to align with SD goals remains complex. This study aims to assess the current state of Lean practices in modular construction and their implications for the triple bottom line of sustainability. A bibliometric analysis is conducted to explore relationships between these concepts, identifying research gaps, such as limited attention to social aspects and the nuanced dual impacts—both positive and negative—of Lean applications. This literature review contributes to the body of knowledge by providing an in-depth analysis of key trends in Lean practices and off-site construction, their outcomes in sustainable dimensions.

Keywords: Modular off-site Construction (MOC), Sustainable Development, Lean Management

1. INTRODUCTION

Modular Off-site Construction (MOC) is increasingly recognized as a modern construction method with the potential to address major industry challenges such as inefficiency, high waste, and environmental impact. It offers advantages including faster project delivery, improved quality, and reduced material usage. These benefits align well with the principles of Sustainable Development (SD), particularly in reducing the construction sector's environmental footprint and improving cost and time efficiency (Kamali et al., 2018). However, despite its promise, MOC still faces implementation challenges such as transportation constraints, design complexity, limited public acceptance, and fragmented supply chains (Hussein & Zayed, 2021). This underscores the need for strategic frameworks to optimize its processes and sustainability outcomes.

Lean Management (LM), a philosophy focused on waste elimination, continuous improvement, and value creation, has been applied in the construction industry to improve process efficiency. While it originated in manufacturing, Lean's principles are highly compatible with the off-site modular context. Nevertheless, the integration of Lean with MOC to support sustainable outcomes remains underdeveloped (Du et al., 2023). Most studies focus on either Lean and construction, Lean and sustainability, or MOC and sustainability in

isolation. Few studies examine how Lean principles influence all three dimensions of the Triple Bottom Line (TBL) in Modular Off-site Construction (Carvajal-Arango et al., 2019; Goh & Goh, 2019).

Moreover, previous reviews highlight gaps in understanding how Lean tools (e.g., Just-in-Time, Kaizen, Value Stream Mapping) contribute to sustainability across the construction lifecycle. For instance, (Jin et al., 2018) and (Peiris et al., 2023) observed that while methods like Lean, BIM, and IPD are individually discussed in off-site construction, their integration particularly with sustainability is rarely explored. Studies also show a significant imbalance in the treatment of sustainability dimensions: economic aspects dominate the literature, while environmental and especially social dimensions receive limited attention (Carvajal-Arango et al., 2019; Hussein & Zayed, 2021). This lack of holistic analysis and integration points to the need for a structured and targeted review.

This work seeks to answer two key research questions: (a) What are the current research topics and trends regarding the integration of Lean management and sustainability in MOC? (b) What are the research gaps, needs, current activities, and opportunities for future research (research roadmap)? The findings of this review provide an in-depth discussion of emerging trends, critical research gaps, and recommendations for future studies. Ultimately, this review serves as a foundation for optimizing Lean applications in MOC, aiming to achieve a balanced and holistic approach to sustainable development in the construction industry.

2. METHODOLOGY

The study employs a systematic literature review (SLR), combining quantitative and qualitative analyses to offer a comprehensive and nuanced perspective on existing literature. Bibliometric mapping is a well adopted method for visualizing trends and connections in scientific research (Xiao & Watson, 2019). VOSviewer, a bibliometric mapping tool designed to construct and display bibliometric networks. This tool enhanced the clarity and usability of the findings, aiding in the identification of future research areas (Van Eck & Waltman, 2010). Initial Key search terms, such as "Lean Construction," "Modular Off-Site Construction," and "Sustainable Development," were selected based on prominent terms identified in pioneering studies on Lean and modular construction.

Scopus was selected as the primary database due to its wide coverage of peer-reviewed journals in construction, engineering, and sustainability, and its integration with VOSviewer for bibliometric mapping (Hu et al., 2019).

Figure *1* illustrates the PRISMA diagram for the systematic literature search and evaluation process conducted in this study. A structured search was conducted for English-language publications from 2004 to 2024 using the query: (Lean OR “Lean Management”) AND (Sustainability OR Sustainable Development OR Green) AND (Construction OR “Modular Construction” OR “Off-Site Construction” OR MOC), returned 550 records. Filters were then applied to refine results by language (English), document type (journal articles only), subject area (Engineering, Energy, and Environmental Science), and publication year (2004–2024), reducing the dataset to 394 records. After title and abstract screening, 279 records were excluded due to duplication, irrelevance, or being non-journal publications. This left 115 full-text articles for detailed eligibility assessment. A further 50 articles were excluded during full-text review for not sufficiently addressing all three key domains: Lean, Sustainability, and MOC.

Ultimately, 65 studies were selected. To improve coverage, 6 additional studies were identified through backward snowballing (Jayawardana et al., 2023), resulting in a total of 71 key articles. These were analyzed using thematic and bibliometric techniques and categorized under three core themes: Lean Practices, Sustainability, and MOC. Table 1 presents a summary of key contributions across these themes, emphasizing their integration potential.

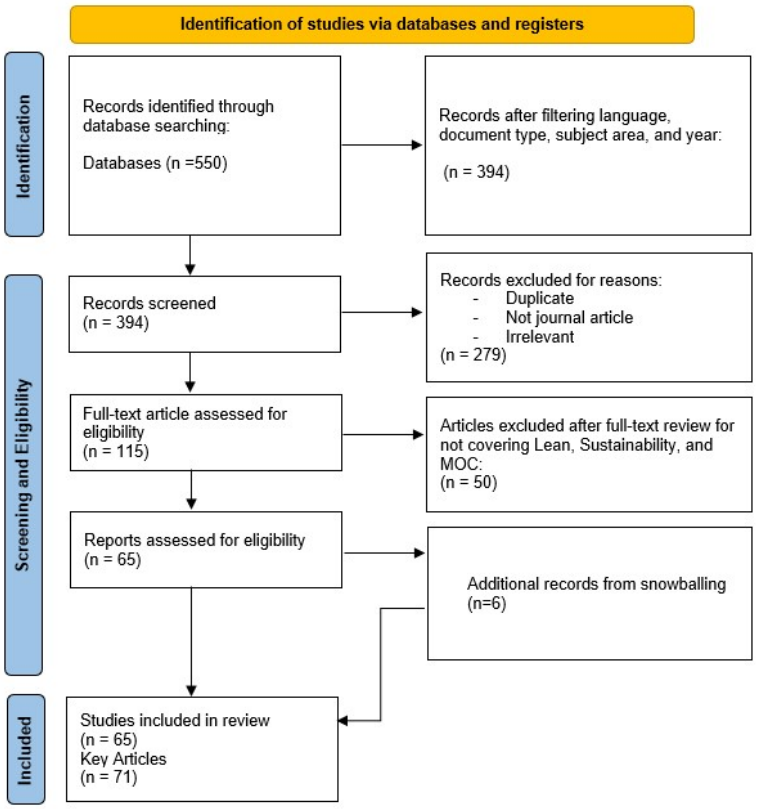

Figure 1 : Literature search and evaluation for inclusion

Table 1 : Comprehensive table of key articles - Sorted by year

No.	Author	Year	Method	Research Theme		
				Lean	SD	MOC
1	A. Singh et al.	2024	Literature Review, AHP Model	•		•
2	Negi et al.	2024	Survey, Exploratory Analysis		•	•
3	Moradi & Sormunen	2023	Systematic Review	•	•	
4	Batwara et al.	2023	Systematic Review (PRISMA)	•	•	
5	Jayawardana et al.	2023	Systematic Review, Bibliometric Analysis		•	•
6	McDermott et al.	2023	Case Study	•		•
7	S. Lee et al.	2023	IPA, Literature Review, Survey	•		•
8	Du et al.	2023	Scient metric, Systematic Review	•		•
9	Pan & Pan	2023	Mixed-method Study	•	•	•
10	Zaalouk & Han	2022	Case Study, Optimization			•
11	Ikram et al.	2022	Literature Review, Conceptual Framework	•	•	
12	Naeemah & Wong	2022	Systematic Review (SLR)	•		
13	Rahima Shabeen & Aravind Krishnan	2022	Case Study			•
14	Assaad et al.	2022	Survey, Interviews, Literature Review		•	•
15	Demirkesen & Bayha	2022	Literature Review, Factor Analysis	•		
16	Moradi et al.	2022	Literature Review, Qualitative Analysis		•	

Table 1: Comprehensive table of key articles - Sorted by year (continued)

No.	Author	Year	Method	Research Theme		
				Lean	SD	MOC
17	Caldarelli et al.	2022	Case Study	•	•	•
18	Han et al.	2022	Literature Review, Bibliometric Analysis			•
19	Mossman & Sarhan	2021	Case Studies, Literature Review		•	•
20	D. Lee & Lee	2021	Case Study, Framework Development			•
21	Jang et al.	2021	Literature Review		•	•
22	Hussein et al.	2021	Review (Scientometric & Systematic)			•
23	Hussein & Zayed	2021	Systematic Review, Meta-analysis		•	•
24	Mellado & Lou	2020	Literature Review, Framework Development	•	•	•
25	J. Singh et al.	2020	Questionnaire, Interviews, SEM	•		
26	Dieste et al.	2020	Case Study, Interviews	•	•	
27	Demirkesen & Bayhan	2020	Literature Review, ANP Model	•		
28	Zhang et al.	2020	Case Study, Framework Development			•
29	Gao et al.	2020	Literature Review, Systematic Review		•	•
30	Gbadamosi et al.	2019	BIM Optimization, DFMA, Lean Construction			•
31	Francis & Thomas	2019	System Dynamics, Conceptual Modeling	•	•	
32	Carvajal-Arango et al.	2019	Literature Review	•	•	
33	Innella et al.	2019	Systematic Review	•	•	•
34	Minh et al.	2019	Survey, Partial Least Squares (PLS)	•		
35	Bridi et al.	2019	Systematic Mapping	•		•
36	Goh & Goh	2019	Case Study, Discrete Event Simulation (DES)	•		•
37	Solaimani et al.	2019	Systematic Review	•	•	
38	Terreno et al.	2019	Review Study	•		
39	Demirkesen, Wachter, Oprach, Haghsheno, et al.	2019	Literature Review, Survey	•		
40	Meng	2019	Literature Review, Questionnaire, Interviews	•		
41	Maqbool et al.	2019	Case Study	•	•	
42	Jiang et al.	2019	Comparative Study, Questionnaire		•	•
43	Peltokorpi et al.	2018	Case Studies, Framework Development			•
44	Souza & Alves	2018	Theoretical Framework, Action Research	•	•	
45	Khodeir & Othman	2018	Literature Review, Correlation Matrix	•	•	
45	Khodeir & Othman	2018	Literature Review, Correlation Matrix	•	•	
46	Kong et al.	2018	Case Study		•	•
47	Caiado et al.	2018	Systematic Review	•	•	
48	Jin et al., 2018	2018	Review		•	•
49	Arashpour et al.	2017	Theoretical Modeling, Precast Production		•	•

Table 1: Comprehensive table of key articles – Sorted by year (continued)

No.	Author	Year	Method	Research Theme		
				Lean	SD	MOC
50	Heravi & Firoozi	2017	Case Study	•		•
51	Cherrafi et al.	2016	Literature Review	•	•	
52	Kamali & Hewage	2016	Review		•	•
53	Mostafa et al.	2016	Systematic Review (SLR)			•
54	Ng et al.	2015	Case Study	•	•	
55	Ko & Kuo	2015	Case Study, Lean Model	•		•
56	Belekoukias et al.	2014	Quantitative Study, Regression, Structural Modeling	•		
57	Martínez-Jurado & Moyano-Fuentes	2014	Literature Review	•	•	
58	Rosenbaum et al.	2014	Case Study		•	
59	Ogunbiyi et al.	2014	Questionnaire Survey	•	•	
60	Yu et al.	2013	Case Study			•
61	Firoozi & Heravi	2013	Survey, Lean Methods, Data Collection			•
62	Boyd et al.	2013	Case Study, Theoretical Analysis		•	•
63	Aziz & Hafez	2013	Review, Case Study	•		
64	Stump & Badurdeen	2012	Case Study	•		
65	Nahmens & Ikuma	2012	Case Studies		•	•
66	Vieira & Cachadinha	2011	Case Study	•	•	
67	Song & Liang	2011	Case Study	•	•	
68	Yang et al.	2011	Empirical Study	•	•	
69	Yu et al.	2009	Case Study, Simulation	•		
70	Abdulmalek & Rajgopal	2007	Case Study, Simulation (Steel Industry)	•	•	
71	Bertelsen & Koskela	2004	Theoretical Analysis, Literature Review	•	•	•

3. QUANTITATIVE ANALYSIS

To identify publications related to the integration and impact of Lean Management on Sustainable Development (SD) in Modular Off-Site Construction (MOC), a systematic search was conducted using Scopus for English-language articles published between 2004 and 2024. Figure *2* illustrates the temporal distribution and thematic coverage of the selected studies. The graph on the right side shows the number of publications per year for each domain. A notable rise in Lean-focused publications is observed after 2019, indicating increased academic interest in Lean practices. The graph also demonstrates a general upward trend across all three themes, underscoring their growing significance in shaping sustainable construction practices.

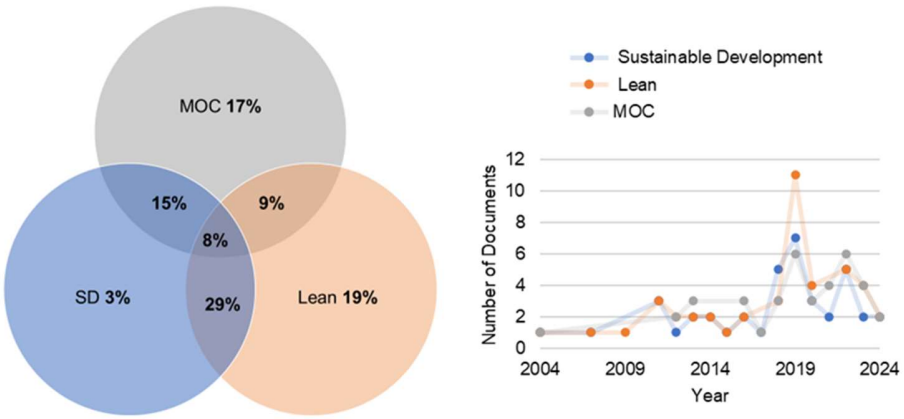

Figure 2 : Left: Venn diagram of topic distribution across SD, Lean, and MOC. Right: Yearly publication trends (2004–2024) showing rising interest and thematic overlap

The Venn diagram (Figure 2 – left) represents the distribution of 71 reviewed studies across the three themes: 8% of studies addressed all three domains (Lean, SD, and MOC); 17% focused only on MOC; 19% on Lean; and 3% solely on SD. Furthermore, 15% examined both MOC and SD, 29% focused on Lean and SD, and 9% addressed Lean and MOC. These percentages reflect both individual and overlapping coverage, offering a more nuanced understanding of research patterns. The relatively low number of studies covering all three areas highlights a gap in integrated approaches.

To investigate sustainability priorities within MOC-related studies, a qualitative coding process was conducted using NVivo 14, following the methodological framework of (Skjott Linneberg & Korsgaard, 2019). The analysis was carried out in two stages. First, a deductive coding strategy was applied based on the three pillars of sustainability—economic, environmental, and social—as parent nodes. Codes were generated by reviewing key articles from the dataset, aligning with prior practices for qualitative systematic reviews (Lewins & Silver, 2009). In the second stage, word frequency analysis was used to refine sub-categories and detect recurring patterns, ensuring a systematic and replicable interpretation of the literature. This method allowed for a data-driven understanding of the emphasis placed on each sustainability dimension(Wong, 2008).

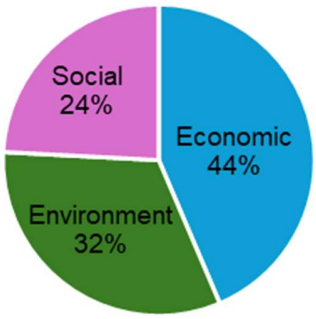

Figure 3 : Aspects of Sustainable Development (SD) in Modular Off-site Construction (MOC)

Figure 3 presents the distribution of sustainability aspects discussed in the reviewed studies. Economic sustainability appeared in 44% of the publications, followed by environmental sustainability at 32%. Social sustainability, however, was addressed in only 24% of the studies, making it the most underrepresented dimension. These findings underline the need for a more balanced integration of social concerns into Lean-MOC frameworks, especially considering the broader goals of sustainable development.

In addition to thematic analysis, bibliometric data from Scopus was analyzed using VOS viewer to examine patterns of international collaboration and keyword co-occurrence. Table 2 highlights countries with more than five publications in the selected domains. The USA, China, and England emerged as leading contributors, both in publication volume and citation impact, indicating their central role in advancing research in Lean, MOC, and sustainability. Countries like Canada, Australia, and the Netherlands also demonstrated notable collaboration networks, as reflected in their total link strength values.

Table 2 : Countries with more than 5 publications in MOC,Lean,SD

Country	Documents	Citations	Total Link Strength
China	10	701	6
England	7	919	5
USA	13	2167	5
Netherlands	5	232	4
Australia	10	691	3
Canada	7	708	2
South Korea	3	57	1
Chile	3	122	1
India	4	55	1
Italy	5	361	1
Brazil	3	181	0
Malaysia	3	142	0

Keyword co-occurrence analysis further reveals major research clusters and thematic interconnections. Figure 4 generated via VOS viewer, displays a network of frequently occurring terms (minimum three occurrences), with prominent keywords including "performance," "sustainability," "lean construction," and "prefabrication." Table 3 lists the top 15 most frequent terms alongside their total link strength. The findings show strong associations between Lean principles and performance/sustainability outcomes. However, the relatively weaker linkage between Lean and modular/prefabrication terms suggests a gap in integrating Lean with MOC practices.

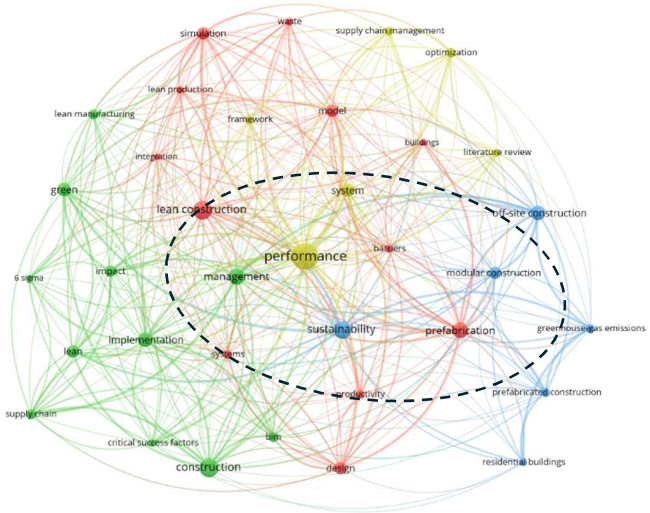

Figure 4 : Keyword co-occurrence map (generated with VOS Viewer)

Collectively, these results provide a comprehensive view of the current research landscape. While lean and sustainability have been extensively studied, their joint application in modular construction remains limited. Addressing this gap can unlock new insights into optimizing sustainable outcomes in MOC through Lean principles. Future studies should prioritize exploring how Lean principles can enhance the efficiency, resilience, and sustainability of MOC.

Table 3 : Top 15 high occurrence keywords in MOC, Lean, SD

Ranking	Keyword	Occurrences	Total Link Strength
1	Performance	24	112
2	Management	14	69
3	Prefabrication	13	64
4	Implementation	12	61
5	System	11	61
6	Construction	16	56
7	Lean Construction	13	55
8	Sustainability	15	55
9	Off-site Construction	12	53
10	Green	11	50
11	Design	10	46
12	Simulation	10	46
13	Impact	9	45
14	BIM	10	44
15	Model	10	43

4. QUALITATIVE ANALYSIS

The qualitative analysis presented in this study is part of an ongoing comprehensive research initiative aimed at identifying the critical success factors for integrating Lean principles into MOC to optimize Sustainable Development (SD), with a particular focus on its social dimension. To achieve this, key articles included in the SLR were analyzed to uncover potential factors contributing to the successful implementation of Lean practices in MOC projects. The classification of research themes, as outlined in Table 1, indicates the specific focus areas and methodological approaches of each study, based on keyword co-occurrence analysis and a rigorous abstract screening process.

4.1 COMBINATION OF LEAN MANAGEMENT, SUSTAINABLE DEVELOPMENT, AND MOC

Prefabricated construction involves demanding management requirements across its design, prefabrication, and construction stages, making traditional construction management methods insufficient to meet these demands. In contrast, Lean principles align well with prefabricated construction management, as both focus on reducing waste and shortening project timelines. Koskela formally incorporated Lean principles into construction, introducing the Transformation, Flow, and Value Generation (TFV) theory as a structured framework(Du et al., 2023).Lean management in modular construction offers a wide range of benefits, particularly in economic, environmental, and social sustainability. Numerous case studies highlight economic advantages, such as productivity increases of up to 40%–50%, lead time reduction, waste minimization, cost reduction, and higher throughput (Innella et al., 2019; Nahmens & Ikuma, 2012).Beyond economic gains, Lean principles enhance sustainability by improving safety and job satisfaction and reduced pollution (Innella et al., 2019).

Several studies have explored the intersection of these three domains, demonstrating the potential benefits and challenges of their combined implementation. Their findings suggest that while economic and environmental benefits are well documented, achieving an optimal balance across all three sustainability dimensions remains complex due to trade-offs, such as the higher upfront costs of energy-efficient modular buildings(Kamali et al., 2018).Similarly, (Peiris et al., 2023) identified a gap in the application of Lean construction principles for the development of Manufacturing Execution & Control (MEC) systems within MOC, underscoring the need for more structured Lean-MOC integration. While Lean principles and sustainability objectives share common goals such as waste minimization and resource efficiency, their practical integration in MOC remains inconsistent. Furthermore, (Khodeir & Othman, 2018) emphasized that Lean tools, particularly Just-in-Time (JIT) and Value Stream Mapping (VSM), can improve sustainability metrics in MOC projects. However, (Martínez-Jurado & Moyano-Fuentes, 2014) cautioned that JIT

strategies, while improving production flow, could inadvertently increase supply chain environmental impacts if not carefully managed.(Kamali et al., 2018) mentioned that existing research primarily focuses on economic and environmental aspects, while the social dimension of sustainability remains underexplored. For example, (Batwara et al., 2023) highlighted the need to integrate social sustainability considerations—such as worker well-being, job stability, and community impact into Lean tools like VSM. Additionally, (Demirkesen & Bayhan, 2020) noted that MOC differs from traditional manufacturing due to its variability in project designs, stakeholder dynamics, and site conditions, which complicate Lean adoption. As (Moradi & Sormunen, 2023) mentioned the success, challenges, and impact of integrating Lean Construction and sustainability are deeply connected to people their mindset, collaboration, and adaptability. For example, these challenges are further amplified by fragmented implementation practices across regions, such as in Hong Kong, where standardization remains a key issue. Similarly, (Sarhan & Fox, 2013) identified cultural resistance within the UK construction industry as a major barrier to Lean adoption, highlighting the need for a systematic framework that aligns Lean principles with MOC workflows. Hence, future research should adopt qualitative methodologies, including semi-structured interviews with industry professionals, worker satisfaction surveys, and case studies on successful Lean-MOC implementations (Demirkesen & Bayhan, 2020). Additionally, integrating Lean principles with Human-Centered Design (HCD) could enhance ergonomics, safety, and labor welfare considerations, thus strengthening the social sustainability of MOC projects (Gbadamosi et al., 2019).

5. CONCLUSION

This study examines the integration of Lean Management, Modular Off-Site Construction (MOC), and sustainability to improve economic, environmental, and social outcomes in the construction industry. The findings highlight significant progress in these areas but also reveal clear gaps particularly in integrating Lean tools within MOC to comprehensively address sustainability across its three dimensions. The study confirms that Lean practices enhance sustainability through reduced waste, improved efficiency, and streamlined processes. However, several limitations should be noted, including the focus on English-language publications, the exclusion of empirical validation, and limited attention to emerging technologies such as AI and IoT in Lean-MOC applications. Future research should concentrate on developing structured frameworks that link Lean tools to MOC workflows specifically in design, production, and on-site assembly. Further studies should also investigate how Lean can overcome challenges unique to MOC, such as logistical complexity and fragmentation, while expanding the examination of social sustainability within these systems. Additionally, simulation-based and life-cycle analyses could help quantify Lean-MOC impacts, offering deeper insights into their long-term economic and environmental performance.

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