



Modular and offsite Construction Summit

July 28-31, 2025 Montreal, Canada

Navigating Barriers to the Adoption and Scalability of Modular Construction in Ethiopia

Tadesse ZELELE^{1*}, Muluken DESBALO², Ahmed BOUFERGUENE³ and Mohamed AL-HUSSEIN⁴

¹ Post-Doctoral Fellow, Dept. of Civil and Environmental Engineering, University of Alberta

² PhD candidate, School of Built Environment, Addis Ababa University

³ Professor, Dept of Civil and Environmental Engineering, University of Alberta

⁴ Professor, Dept of Civil and Environmental Engineering, University of Alberta

*Corresponding author's e-mail: zelele@ualberta.ca

ABSTRACT

As a developing economy, there is an increasing demand for infrastructure in Ethiopia that necessitates faster and more scalable construction solutions. Modular construction (MC) offers a viable alternative to conventional methods, but its adoption is hindered by systemic barriers. This study identifies and analyze key barriers influencing the scalability of MC in Ethiopia. Data has been collected through expert surveys involving 34 participants, including policymakers, manufacturers, academia, and construction professionals. The study applies a fuzzy DEMATEL method to quantify interdependencies among six critical barriers. The findings reveal that *policy and government support (BR1)* acts as a primary driver, influencing downstream barriers such as *supply chain resilience (BR2)* and *process efficiency (BR5)*. Conversely, financial constraints and fragmented supply chains emerged as high-impact barriers requiring policy intervention. Based on the findings, the study further proposes a strategic framework advocating for public-private partnerships, workforce upskilling, and digital integration to enhance modular construction scalability. By leveraging Fuzzy-DEMATEL analysis, the study bridges the gap between theoretical research and practical implementation, offering actionable insights for policymakers and investors. A limitation of this study is its reliance on a limited pool of expert opinions; however, such studies typically draw insights from five to 20 experts. Further more, this limitation was mitigated through the application of fuzzy logic.

KEYWORDS

Fuzzy DEMATEL; Modular construction; Policy intervention; Scalability and adoption; Ethiopia

INTRODUCTION

The construction industry plays a pivotal role in global economic growth, driving urbanization, infrastructure expansion, and job creation. However, due to its resource-intensive nature, the industry continues to grapple with persistent challenges, including inefficiencies, high material waste, labour shortages, and significant environmental impacts (Jayawardana et al., 2024; Ribeiro et al., 2022). In response to these challenges, innovative approaches such as digital transformation and modular construction (MC) are reshaping construction practices by offering more efficient, sustainable, and scalable solutions (Feldmann et al., 2022; Mao et al., 2015; Marinelli et al., 2022). For instance, the integration of Building Information Modelling (BIM), Digital Twins (DT), the Internet of Things (IoT), and blockchain has revolutionized project planning, execution, and

monitoring, enhancing productivity while minimizing waste (Feldmann et al., 2022; Jayawardana et al., 2024).

However, many developing nations, including Ethiopia, lack the necessary digital infrastructure and skilled personnel, hindering widespread adoption (Oyefusi et al., 2024). MC, as an industrialized construction method, shifts a substantial portion of work offsite to controlled factory environments, enabling better quality control, faster project completion, and reduced environmental impact (Ribeiro et al., 2022). Research has shown that MC can accelerate project delivery by up to 50% while cutting material waste by 84% (Chourasia & Singhal, 2023). Countries with advanced modular practices, such as Singapore and Sweden, have leveraged these benefits to address housing shortages and enhance sustainability (Navaratnam et al., 2022). Despite its potential, MC adoption remains limited, particularly in developing economies, due to financial, technological, regulatory, and market-related barriers (Ribeiro et al., 2022). Ethiopia, undergoing rapid urban expansion and increasing infrastructure demands, presents a compelling case for the adoption of modular construction. MC offers a viable alternative, particularly in post-disaster recovery and emergency housing, where rapid deployment of schools, healthcare centers, and residential units is critical (Chourasia & Singhal, 2023). However, the absence of clear regulatory frameworks, limited R&D investment, and weak industry awareness hinder its widespread implementation in Ethiopia (Rangasamy & Yang, 2025; Yao & Gurmu, 2024). Hence, the present study aims to identify and analyze the key barriers hindering the adoption and scalability of MC in Ethiopia by examining the technological, regulatory, and market-related constraints affecting its implementation.

IDENTIFICATION AND CATEGORIZATION OF BARRIERS

Numerous studies have identified challenges in adopting and expanding modular construction (MC). These barriers have been examined across different regions, revealing recurring themes and context-specific issues. In Australia, Navaratnam et al. (2022) categorized the primary barriers into six key aspects: cultural, economic, practical, sustainable, technical, and other influences. Similarly, in Egypt, Ali et al. (2023) identified 30 barriers and grouped them into five main categories: attitudinal, knowledge, technical, financial, and process-related challenges. These studies highlight the multifaceted nature of MC barriers, emphasizing the interplay between cultural, economic, and technical factors. Moving to Sri Lanka, Jayawardana et al., (2024) examined barriers to MC adoption and initially identified 23 obstacles. Using fuzzy synthetic and factor analysis, they consolidated these obstacles into six major categories: industry and technical knowledge; awareness, communication and perceptions; operations management and logistics; policy, standards, and technical guidance; market and aesthetics; and economic challenges.

In Asia, several studies have explored MC barriers. A systematic review of prefabricated housing challenges in China highlighted five key thematic barriers: negative perception, limited public understanding, risk-averse culture, lack of green value, and concerns about unemployment rates. Similarly, Yao & Gurmu (2024) investigated MC barriers in China, emphasizing the role of cultural and economic factors. In Taiwan, Rangasamy & Yang (2025) prioritized 18 critical barriers out of 41 using the ISM-MICMAC approach. Their recommendations were classified into seven categories: investment and supply chains; bidding, contracts, and government policy simplification; design, technical limitations, and regulations; training, education, and knowledge development; labour, managerial challenges, and skills; industry attitudes; and advanced

technology and innovation. These studies collectively highlight the importance of policy support, technical innovation, and workforce development in overcoming MC barriers in Asian markets. In Germany, Feldmann et al. (2022) employed a Fuzzy-DEMATEL analysis and identified eight major barriers: regulatory, financial, technical, supply chain, demand, knowledge, industry attitude, and process-related challenges. This study provides a comprehensive framework for understanding the interconnected nature of MC barriers in a developed economy. Finally, in Chile, Ortega et al. (2023) conducted a comprehensive literature review followed by expert panel discussions to identify the top barriers from a total of 74. These barriers were categorized into ten broad groups: cultural, quality, market, financial, design and development, innovation and technology, workforce skills, policies and regulations, documentation and communication, and logistics. The study highlights the complexity of MC barriers in a Latin American context, emphasizing the need for holistic strategies to address diverse challenges. Additionally, other studies, such as those conducted by Zhang et al. (2018) in Hong Kong, have contributed to the global understanding of MC barriers, further enriching the literature with region-specific insights.

In Nigeria, Oyefusi et al. (2024) applied the Fuzzy-AHP method to categorize 20 barriers into five broad themes: individual, organizational, economic, regulatory, and technical challenges. Similarly, Bello et al. (2024) explored modular construction barriers in Nigeria and South Africa through a survey, identifying nine main categories: financial, operational, government-related, knowledge, technical, logistics, industry, attitude, and aesthetics. These studies highlight the significance of regulatory frameworks and financial constraints in shaping MC adoption in African contexts.

Overall, the existing literature highlights diverse challenges to the growth and scalability of MC across different regions. These studies provide valuable insights into recurring themes, such as financial constraints, regulatory hurdles, and cultural perceptions, as well as context-specific issues, informing strategies for addressing and mitigating these barriers. This study underscores the importance of addressing both industry-specific and societal perceptions in promoting MC adoption in developing countries considering the Ethiopian context. Building upon a systematic review of the existing literature, this study systematically classifies the barriers to the scalability of MC into six primary categories. These categories capture the multifaceted challenges identified across diverse scholarly sources, ensuring a comprehensive representation of the key barriers impeding MC's widespread adoption and scalability. By synthesizing insights from prior studies, the categorization provides a structured framework for analysis of the complex interaction between policy, technology, supply chains, organizational culture, process efficiency, and market dynamics in the modular construction sector. The identified barriers, along with their descriptions and supporting references, are presented in Table 1.

Table 1. Categories of barriers.

Categories of barriers	Description	Reference
<i>Policy and Government Support (BR1)</i>	In many developing countries, the absence of modular-specific regulations, outdated building codes, and lack of certification standards significantly hinder MC adoption. Limited fiscal incentives, such as tax breaks and subsidies, discourage private-sector investment. High capital costs for manufacturing, transportation, and installation necessitate regulatory modernization and public-private partnerships (PPPs) to de-risk investment and ensure financial viability. Lessons from China, the UK, and Australia emphasize the importance of government-backed policies in driving modular construction scalability.	(Q. Wang et al., 2023) (Rangasamy & Yang, 2025) (Jayawardana et al., 2024; Langston & Zhang, 2021; Mao et al., 2015; Oyefusi et al., 2024; Zhang et al., 2018)
<i>Supply Chain Management (BR2)</i>	MC relies on a well-structured logistics network, yet challenges such as transportation bottlenecks, limited road infrastructure, and site-access constraints lead to inefficiencies. The absence of specialized transport systems for oversized modules exacerbates delays and increases costs. Additionally, fragmented supplier networks, inconsistent material availability, and reliance on imports lead to high procurement costs, affecting economies of scale. In countries like Nigeria and Egypt, weak supply chain integration has significantly slowed modular construction adoption.	(Jayawardana et al., 2024; Navaratnam et al., 2022; Oyefusi et al., 2024; Thurairajah et al., 2023)
<i>Technology and Innovation (BR3)</i>	The lack of modular-specific R&D investment, low adoption of digital tools (BIM, AI, IoT), and limited technical expertise create significant barriers to MC scalability. Many developing markets lack accredited quality certification bodies for prefab components, limiting market confidence. Design rigidity, particularly in seismic-prone regions, remains a challenge, requiring advancements in adaptable connection systems. Countries like Taiwan and China have addressed these challenges through investment in modular R&D and digital integration.	(Feldmann et al., 2022; Rajanayagam et al., 2021; Ribeiro et al., 2022; Q. Wang et al., 2023)
<i>People and Organization al l Culture (BR4)</i>	Perceptions of modular construction as inferior in quality, cost-inefficient, and risky contribute to stakeholder resistance. Construction firms, developers, and clients often favour traditional methods due to cultural inertia and risk aversion. Moreover, lack of structured training programs and limited industry awareness slows workforce readiness for modular techniques. Countries like Australia and the UK have successfully mitigated these barriers through targeted education programs and modular construction awareness initiatives.	(Ali, Kineber, Elyamany, Hussein Ibrahim, et al., 2023; Mao et al., 2015; Marinelli et al., 2022; Oyefusi et al., 2024; Thurairajah et al., 2023)
<i>Process Efficiency (BR5)</i>	Inefficiencies in design-manufacturing-assembly integration, supply chain coordination, and stakeholder collaboration lead to misaligned project timelines. In many cases, factories produce modules faster than site readiness, causing storage issues and logistical delays. Fragmented project workflows further impact MC efficiency, requiring enhanced coordination strategies, as observed in China, Portugal, and Singapore.	(Ali, Kineber, Elyamany, Ibrahim, et al., 2023; Navaratnam et al., 2022; Nguyen & Pishdad-Bozorgi, 2023; Rangasamy & Yang, 2025; Thurairajah et al., 2023; Zhang et al., 2018)
<i>Market Demand (BR6)</i>	Public and private sector hesitation towards modular adoption stems from limited awareness of its benefits (cost savings, sustainability, speed) and lack of economic incentives. The immaturity of specialized component supply chains further inflates costs, preventing large-scale adoption. In China and Australia, government-backed awareness campaigns and financial support mechanisms have helped stimulate market demand and lower costs.	(Feldmann et al., 2022; Mao et al., 2015; Marinelli et al., 2022; Rangasamy & Yang, 2025; Q. Wang et al., 2023; Yao & Gurmu, 2024)

Finally, a conclusion and policy recommendations that provide actionable insights for stakeholders to enhance the adoption of MC were made in accordance with the findings (See Figure 2). This structured approach ensures methodological rigor while offering data-driven insights into the interdependencies among barriers, ultimately guiding policy and industry interventions in the Ethiopian construction industry.

METHODOLOGY

This study employed a mixed-methods sequential exploratory design to systematically identify, evaluate, and interpret the barriers to the adoption and scalability of MC in Ethiopia. The methodology comprised three key phases: (1) identification of barriers through systematic literature review, ensuring alignment with existing theoretical frameworks on emerging construction technologies in developing economies; (2) design and administration of survey using DEMATEL, where a structured questionnaire was developed and distributed to industry experts for pairwise influence assessment and computational analysis, incorporating fuzzy logic, followed by the application of Fuzzy DEMATEL approach; (3) results synthesis and discussion, where total and net influence scores were analyzed to distinguish between driving and dependent factors, supported by network visualization techniques, and; (4) a conclusion and policy recommendations that provide actionable insights for stakeholders to enhance the adoption of MC were made (see Figure 2). This structured approach ensures methodological rigor while offering data-driven insights into the interdependencies among barriers, ultimately guiding policy and industry interventions in the Ethiopian construction industry.

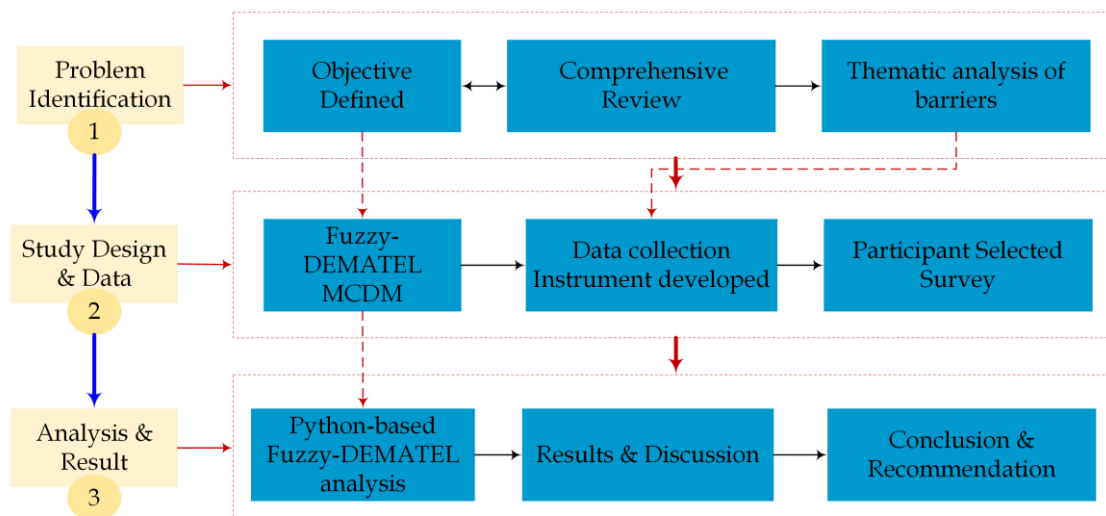


Figure 1. Study process flow.

Fuzzy-DEMATEL Analysis for Interdependencies among Barriers

This method extends the traditional DEMATEL approach by incorporating fuzzy set theory that enables to handle the inherent ambiguity and subjectivity in expert judgments. The process proceeds through the following key steps:

Procedure for Fuzzy DEMATEL Analysis

1. **Identification of Factors and Experts' Evaluation:** A panel of experts provided pairwise influence ratings using linguistic terms to identify and evaluate key barriers affecting the

system. Ratings were collected in linguistic terms (e.g., "Low", "Medium", "High") and converted into Triangular Fuzzy Numbers (TFNs).

2. **Fuzzification of Expert Judgments:** The linguistic terms were mapped to Triangular Fuzzy Numbers, which is a type of fuzzy number represented by three values (the smallest possible value, the most likely value, and the largest possible value) as shown in Table 2.

Table 2. Fuzzy linguistic scale and TFNs.

Linguistic Term	Scale	TFN Representation
Very Low (VL)	0	(0.00, 0.00, 0.25)
Low (L)	1	(0.00, 0.25, 0.50)
Medium (M)	2	(0.25, 0.50, 0.75)
High (H)	3	(0.50, 0.75, 1.00)
Very High (VH)	4	(0.75, 1.00, 1.00)

Then, aggregated expert judgments were compiled into the Fuzzy Direct-Relation Matrix (FDRM) using equation (1):

$$\tilde{D} = \begin{bmatrix} \tilde{d}_{11} & \tilde{d}_{12} & \cdots & \tilde{d}_{1n} \\ \tilde{d}_{21} & \tilde{d}_{22} & \cdots & \vdots \\ \vdots & \cdots & \ddots & \vdots \\ \tilde{d}_{n1} & \tilde{d}_{n2} & \cdots & \tilde{d}_{nn} \end{bmatrix} \quad (1)$$

3. **Normalization of the Fuzzy Direct-Relation Matrix**, given by equation (2):

$$\tilde{D}^* = \tilde{D} \times \frac{1}{\text{Max} \left(\sum \tilde{D}_{ij} \right)} \quad (2)$$

4. **Computation of the Fuzzy Total Influence Matrix (Fuzzy TRM).** The total influence matrix $\tilde{T}$ was computed using the inverse matrix approach, defined as (3). This matrix captures **direct and indirect** influence relationships.

$$\tilde{T} = \tilde{D}^* \times (I - \tilde{D}^*)^{-1} \quad (3)$$

5. **Defuzzification of the Total Influence Matrix:** After computing $\tilde{T}$ defuzzification was applied to obtain a crisp Total Influence Matrix (TRM). The Centroid Method (Mean of Maximum - MOM) provides a balanced judgement, equation (4):

$$T_{ij} = \frac{(l_{ij} + m_{ij} + u_{ij})}{3} \quad (4)$$

6. **Threshold Determination and Network Visualization:** Plot the factors on a two-dimensional diagram where the horizontal axis represents $(R + D)$ (prominence) and vertical axis $(R - D)$ their cause-effect relationship as shown in the equation (5):

$$\alpha = \frac{\sum_{i=1}^n \sum_{j=1}^n [t_{ij}]}{p^2} \quad (5)$$

where p represents the number of factors in the system.

To filter significant influences, two threshold values were tested. The Mean Value of TRM elements and the 75th percentile (higher threshold, fewer connections) were used as a sensitivity analysis.

7. **Calculate Influence Scores:** Factors with high $(R + D)$ values are central to the system and have strong interactions with other factors. $(R - D)$ is net cause or net effect. If $(R - C)$ is positive, the factor is a net cause (influencer). It has a greater influence on other factors than it receives. If $(R - D)$ is negative, the factor is a net effect (influenced). It is more influenced by other factors than it influences, equations (6) , and (7).

$$(R + D)_i = \sum_i T_{ij} + \sum_j T_{ji} \quad (6)$$

$$(R - D)_i = \sum_i T_{ij} - \sum_j T_{ji} \quad (7)$$

RESULT AND DISCUSSION

A structured DEMATEL questionnaire was developed to evaluate the influence of each barrier identified from literature. The questionnaire consists of three sections: respondent expertise, years of experience, and project involvement. The initial questionnaire underwent expert validation by five professionals with more than 10 years of relevant experience, leading to revisions that enhanced clarity and contextual relevance. The questionnaire was sent to 98 professionals who are purpose selected based their exposure on MC across Ethiopian public and private sectors. The participants consisted of construction professionals (58.82%) and researchers (29.41%), ensuring a well-balanced industry-academic perspective. A majority (52.94%) had over 16 years of experience, reflecting deep expertise in the field. Furthermore, 64.71% had prior exposure to MC, with most engaged at the level of building structural elements, as shown in Table 3.

Table 3. Demographic information of respondents.

Description	Characteristics	(N)	%	Total
Employment Category	Construction Professional	20	58.82%	34
	Academic/Researcher	10	29.41%	
	Industry Consultant	5	14.71%	
Professional Experience	1 to 5 years	2	5.88%	34
	6 to 10 years	4	11.76%	
	11 to 15 years	10	29.41%	
	Over 16 years	18	52.94%	
Professional Background	Civil Engineering/Related	29	85.29%	34
	Electrical/ Mechanical Engineering	2	5.88%	
	Other	3	8.82%	
Exposure to MC	Yes	22	64.71%	34
	No	10	29.41%	
	Maybe	2	5.88%	
Level of Exposure of MC	At entire building (module)	2	5.88%	32
	Building structural elements	22	64.71%	
	Other components (such as door, windows, walls)	6	17.65%	
	No MC exposure	2	5.88%	

By mapping the datasets to $(D + R)$ and $(D - R)$ as described in the previous section, the network diagram and causal diagram have been generated and provided in Figures 3 and 4, respectively.

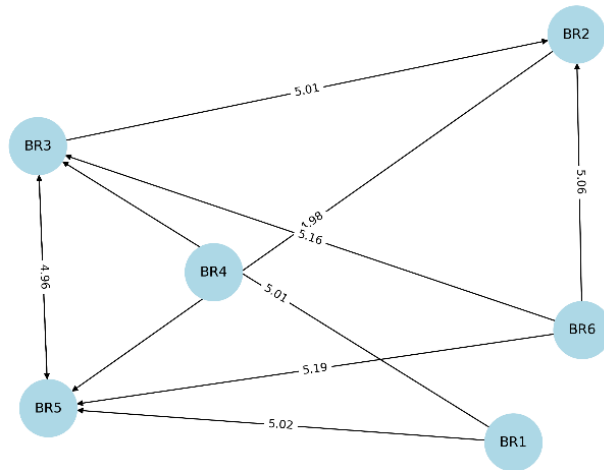


Figure 2. Influence network diagram

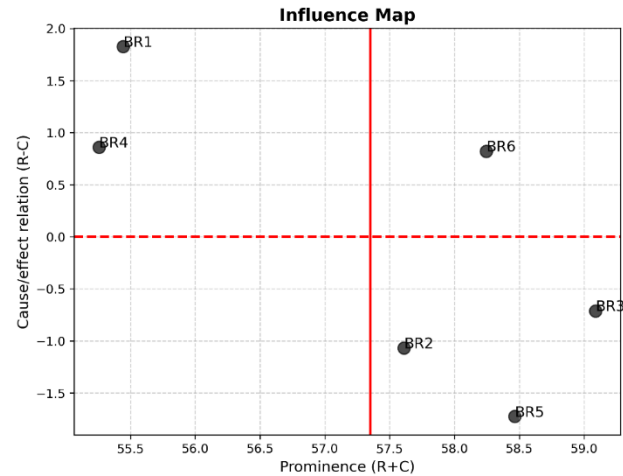


Figure 3. Cause and effect relationship.

Based on the aggregated responses of all experts, the total relation matrix T with the corresponding D and R values was obtained (see Table 4).

Table 4. Total relation matrix T .

	BR1	BR2	BR3	BR4	BR5	BR6	D_i
BR1	4.088	4.649	4.751	4.303	4.779	4.558	27.129
BR2	4.158	4.435	4.670	4.240	4.730	4.506	26.740
BR3	4.297	4.729	4.661	4.374	4.873	4.630	27.565
BR4	4.121	4.528	4.616	4.065	4.678	4.449	26.457
BR5	4.163	4.596	4.689	4.261	4.579	4.510	26.798
BR6	4.364	4.794	4.891	4.438	4.932	4.549	27.968
R_i	25.191	27.731	28.279	25.681	28.571	27.202	

DISCUSSION

The fuzzy DEMATEL analysis in this study provided key insights into the interdependencies among barriers to the adoption and scalability of MC in Ethiopia. The results highlighted that technology and innovation (BR3) exerted the strongest total influence, reinforcing previous studies that emphasize the role of digital tools, such as building information modelling (BIM), artificial intelligence (AI), and digital twins (DT), in advancing modular construction. This finding aligns with research conducted in China and Nigeria, where limited digital adoption has been identified as a key bottleneck to modular construction growth (Oyefusi et al., 2024; I. Wang et al., 2024; Q. Wang et al., 2023).

Similarly, Policy and Government Support (BR1) emerged as a strong driving factor, consistent with prior research indicating that regulatory frameworks significantly impact modular construction adoption.

The findings agree with the finding of a studies in Australia and Taiwan that pointed out how government intervention through subsidies, standardization, and mandatory policy integration has facilitated the wider acceptance of prefabricated methods (Bello et al., 2024; Navaratnam et al., 2022). Additionally, barriers related to supply chain robustness (BR2) and process efficiency (BR5) were found to be highly dependent on other factors, reinforcing global findings that a fragmented supply chain, high initial costs, and transportation challenges are among the major inhibitors of modular construction scalability (Ali, Kineber, Elyamany, Hussein Ibrahim, et al., 2023; Bello et al., 2024). The Ethiopian context is not different from Nigeria and Egypt, who suffers from an underdeveloped supply chain, further exacerbating cost challenges and discouraging private sector participation (Ali et al., 2023; Oyefusi et al., 2024). A key contrast between this study and previous research is the relative impact of market demand (BR6). While demand was found to be a moderate driver in Ethiopia, studies in China, Australia, and Europe, however, highlighted consumer perception and education as significant barriers (Q. Wang et al., 2023; Yao & Gurmu, 2024). Negative public perception, cultural resistance, and lack of awareness regarding the benefits of modular construction have limited the adoption in these regions, suggesting that addressing public concerns through targeted educational initiatives can be an effective strategy for boosting market acceptance (Yao & Gurmu, 2024).

CONCLUSION AND RECOMMENDATION

The findings of this study confirm that modular construction in Ethiopia faces multi-faceted challenges, with policy, technology, and supply chain inefficiencies playing critical roles in determining scalability. These results are in line with previous studies across developing and developed countries, reinforcing the critical role of government-driven initiatives and industry collaboration in overcoming barriers. To accelerate the adoption of MC in Ethiopia, a coordinated effort from policymakers, industry stakeholders, and academic institutions is essential. Based on study findings and global best practices, the following recommendations are proposed:

- **Regulatory Standardization:** MC should be formally recognized in Ethiopia's building regulations by establishing clear design standards, approval processes, and quality control measures. Developing a national certification system for prefabricated components will enhance credibility and facilitate market adoption.
- **Building Code Integration:** Prescriptive and performance-based requirements for modular buildings should be incorporated into Ethiopia's building codes to ensure structural integrity, fire safety, and sustainability, aligning with successful implementations of best practices in Australia, China, and Portugal.
- **Government Incentives:** Financial incentives such as tax exemptions, low-interest loans, and subsidies should be introduced to encourage private-sector investment in modular construction. Additionally, public-private partnerships (PPPs) can help establish local prefabrication manufacturing plants, reducing reliance on imported materials.
- **Education and Workforce Development:** Universities, TVETs, and research institutions should develop specialized courses on modular construction, BIM, AI, and digital fabrication to address the skilled gap.

This study provides a structured foundation for decision-makers, demonstrating that policy-driven interventions have the potential to trigger cascading improvements across multiple barriers, ultimately driving modular construction scalability. Future research should expand on these

insights by incorporating other MCDM methods such as Interpretive Structural Modelling (ISM) and Analytical Hierarchy Process (AHP) for deeper hierarchical analysis of interdependencies.

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