"An Analysis of the Determinants Influencing Modular Construction in the Philippines: A Case Study in Bulacan"

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Abstract: The research analyzes the determinants behind modular construction adoption in Bulacan's privately held residential and commercial buildings in the Philippines. The study investigates the factors that influence the acceptance of modular construction within private residential and commercial buildings located in Bulacan province. The initial reluctance to implement modular construction exists because of delivery complications, financial constraints, workforce shortages, and a general lack of awareness. Survey and interview results examined perceptions of engineering students and industry professionals based on the Theory of Planned Behavior (TPB) and the Analytic Hierarchy Process (AHP) analysis. The research concludes that timeline (17.1%) is the strongest component that promotes adoption of modular construction in Bulacan, followed by risk perception (10.2%), and cost-effectiveness (10.0%). These are major indicators of the industry in terms of quicker project completion, dependability, and financial viability. Conversely, durability, sustainability and initial expendable costs are the least, signifying persistent uncertainty and little knowledge of modular techniques in these domains. The logical consistency of the analysis is verified through a CR value of 0.00885, confirming coherence. The study supports how modular construction provides environmentally efficient designs while reducing operational energy consumption, which helps achieve sustainable development goals. Existing regulations fail to accelerate modular adoption despite the implementation of the Green Building Code. Research findings show that modular construction can deliver energy-efficient designs with reduced operational energy use. Yet, the industry needs both specialized educational programs and more substantial policy support to increase its adoption. This research demonstrates the significance of addressing attitudinal barriers and economic obstacles to activate strategic methods meant to close perception gaps, thus promoting sustainable construction alongside modular building development as a practical solution for energy-efficient infrastructure.

Key Words: Modular Construction; Sustainable Construction Practices; Economic and Attitudinal Barriers; Environmental Impact; Modular Construction in Bulacan

1. INTRODUCTION

Modular construction refers to the process of constructing individual building modules off-site in a controlled factory setting before transporting them to the construction site for installation. In other words, it is a method wherein structures are built as individual "modules" in factory-controlled environments and then transported and assembled at the desired location. Compared to traditional construction, modular construction is more cost-saving by up to 25%, and being in a factory-controlled environment can minimize labor and material waste. Additionally, the pre-fabrication speeds up the whole process, allowing for quicker completion [1]. Modular design minimizes greenhouse gas emissions by up to 47% compared to the traditional on-site approach. Additionally, it is also a method for reducing the environmental footprint of the construction sector [2]. Such efficiency is due to the materials commonly used in these modular systems, which include precast reinforced concrete, structural steel, structural insulated panels, timber, and wood for housing projects.

Lambino et al. (2022) identified that the Philippines encounters unfamiliarity and scarce usage of modular construction, even with official backing behind it [3]. However, the promotion of these systems is increasing due to new infrastructure opportunities, such as housing shortages and government initiatives like the "Build, Build, Build" program. Given these, modular construction provides faster construction timelines, quality control, environmental sustainability, long-run cost efficiency, scalability for big projects, and alignment with sustainable urbanization goals. The fast-developing Bulacan Province, located near the Metro Manila region, provides excellent conditions to examine this construction method because it requires new infrastructure, faces multiple disaster risks, and requires sustainable housing solutions. The strategic nature of this location, combined with its fast-growing real estate market, makes it essential to develop faster, cost-effective construction solutions. This study seeks to explore the determinants that influence the adoption of modular construction in Bulacan by analyzing attitudes and perceptions, construction habits, and economic, environmental, and behavioral factors.

2. METHODOLOGY

The study applies both qualitative and quantitative research methodologies in Bulacan, Philippines. A literature review establishes the theoretical foundation by relying on Islam Md Shaharul et al.'s study regarding vital elements that influence Green Building Technology adoption [4]. The application of The Theory of Planned Behavior model measures individuals' feelings about modular construction adoption through assessments of subjective norms and behavioral control perceptions.

This research involves **65 Civil Engineering students, together with graduates** from specific universities in Bulacan who serve as the targeted participants. A **preliminary evaluation** test using **11 aspiring engineering senior high school STEM students** aims to enhance survey clarity before measuring its reliability. Research methods combine interviews with architects and engineers to gain a wide understanding of modular construction aspects concerning technology, society, and money. The descriptive statistical analysis of participant perceptual data provides information that increases our knowledge about the potential of modular construction throughout the area.

2.1 Analytical Hierarchy Process

The AHP template developed by Simon Barnard (SCB Associates Ltd, 2012; simplified in 2016) [5] serves as the basis for organizing the ranking procedure. This tool automates repetitive calculations, ensuring precision in Saaty's fundamental scale from 1/9 (significantly less important) to 9 (extremely more important). The Pairwise Comparison technique helps judgment accuracy through its ability to let decision-makers evaluate elements based on individual characteristics [6]. The foundation of AHP depends on the pairwise comparison method, and adjusting for inconsistency becomes essential because human cognitive limitations sometimes introduce these issues. The AHP framework ranks and prioritizes key factors influencing modular construction adoption through structured steps:

1. **Selection of Criteria**

   Where 15 factors influencing modular construction adoption were identified.

2. **Pairwise Comparison**

   Decision makers assess all criteria against one another using the basic AHP rating system. The construction of the pairwise comparison matrix *(A)*

features this:
where a_{ij} represents the relative importance of criterion *i* compared to criterion *j*. The reciprocal property is maintained:

$$aji = \frac{1}{a_{ij}} \qquad \text{(Eq. 1)}$$

3. **Normalization of Matrix:**

Each column is summed:

$$S_j = \sum_{i=1}^{n} a_{ij} \qquad \text{(Eq. 2)}$$

4. **Priority Vector (Weights Computation)**

Priority weighs W_i are calculated by averaging the row values in the normalized matrix:

$$W_i = \frac{1}{n}\sum_{j=1}^{n} A_{normij} \qquad \text{(Eq. 3)}$$

5. **Consistency Ratio (CR) Calculation**

The Consistency Index (CI) is calculated to assess consistency:

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad \text{(Eq. 4)}$$

where λ_{max} is the principal eigenvalue and n is the number of criteria. The Consistency Ratio (CR) is determined:

$$CI = \frac{CI}{RI} \qquad \text{(Eq. 5)}$$

where *RI* is the Random Index for the given *n*. A CR below 0.1 indicates acceptable consistency.

2.2 Descriptive Statistics and Histogram Analysis

The survey's significant findings are summarized through **mean scores, standard deviation, and median results.** The response distributions that appear in histograms and graphical analyses reveal both substantial strengths and minor weaknesses.

1. **Compute the Mean (Average)**

The mean provides the central tendency of responses for each factor influencing modular construction.

$$\text{Mean } (\bar{x}) = \frac{\Sigma x_i}{N} \qquad \text{(Eq. 6)}$$

2. **Calculate the Standard Deviation**

This shows how much the responses vary from the mean. Subtract each value from the mean, square the results, average them, and take the square root.

$$s = \sqrt{\frac{\Sigma(x_i - \bar{x})^2}{n-1}} \qquad \text{(Eq. 7)}$$

3. **Determine the Median**

Arrange the responses in order and find the middle one.
If there is an odd number of responses:

$$Median = x_{\frac{n+1}{2}} \qquad \text{(Eq. 8)}$$

If an even number of responses:

$$Median = x_{\frac{x_{\frac{n}{2}} + x_{\frac{n}{2}} + 1}{2}} \qquad \text{(Eq. 9)}$$

3. RESULTS AND DISCUSSION

3.1 Overview of Findings

The study revealed mixed perceptions about modular construction between the student respondents and professionals and workers' interviews. The AHP ranked **project timelines (17.1%)** and **cost-effectiveness (10.0%)** as the t**op determinants of adoption,** as well as barriers like high initial costs, limited skilled labor, and design inflexibility.. Interviews with professionals revealed these findings, emphasizing MC's potential for large-scale projects but highlighting challenges in limited supply chains and client acceptance.

3.2 Demographic Profile of Respondents

The respondents were **18-25 years old**, with **32.3% at 21 years old,** 1**8.5% over 21 years old**, and 4**9.2% below, where most were men** at **75.4%.** Respondents were from different schools, such as B**ulacan State University, Baliuag University, NU Baliwag, and Dr.**

Yanga's Colleges. They were all engineering students, most of whom had construction practices or project management courses. Their varied backgrounds contribute different yet appropriate insights into modular construction.

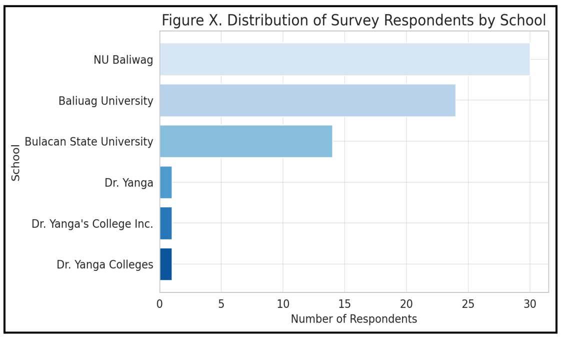


Fig. 1. Distribution of survey respondents by school

Fig. 1 (Distribution of survey respondents by school) comprises 65 students and graduates, showing the survey participants came from student and professional groups. Two civil engineers with 11 years and 4 years of experience, together with an architect with 5 years of experience, participated in the interviews. All respondents performed work tasks inside Bulacan. Students conveyed theoretical aspects, while professional participants contributed their practical field knowledge. The research findings revealed standard and alternative assessment methods regarding modular construction sustainability alongside feasibility and cost-related considerations in Bulacan.

3.3 Analysis of Survey Results

The perception of engineering students in Bulacan about modular construction is presented through survey results that apply the Theory of Planned Behavior framework. The survey data indicates mostly positive views regarding modular building methods while showing some doubts, along with recognition of its affordability values, productivity benefits and sustainability features. However, respondents also highlighted the necessity of better education about these benefits.

Research subjects demonstrated an average understanding of modular construction together with its environmental benefits (mean = 3.73, median = 4) and ecological benefits (mean = 3.96). Research indicates that education about modular construction should be expanded since key information remains unknown to the public.

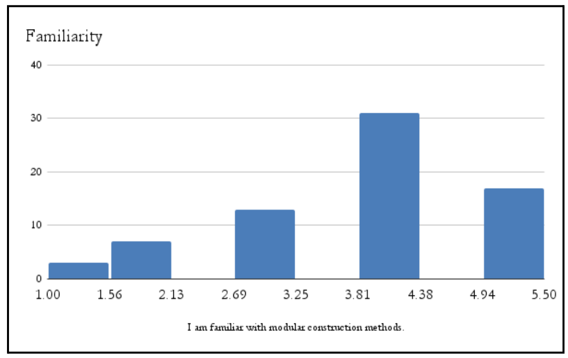


Fig. 2. Histogram of Awareness Levels of MC

As seen in **Fig. 2,** people believe modular construction provides cost-efficiency (mean = 4.03) alongside time efficiency (mean = 4.14), although questions regarding durability (mean = 3.77) require more visible projects to trust.

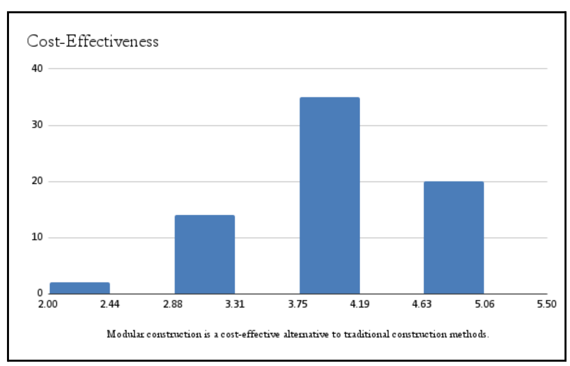


Fig. 3. Histogram of Cost Perception of MC

Peer and mentor support exerts a positive influence on adoption (mean = 3.69), yet non-advocacy groups need to actively promote its usage. As seen in **Fig. 3,** these results indicate that although most peers perceive modular construction positively, increased advocacy and awareness can promote greater acceptance and support for its implementation.

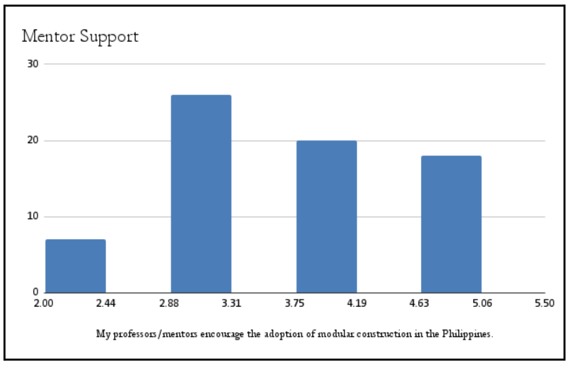


Fig. 4. Histogram of Mentor Support of MC

The survey participants show positive attitudes toward modular construction implementation while stating they have available resources (mean = 3.80 and mean = 3.84, respectively), as reflected in **Fig. 4.** However, they express a need for infrastructure development and training improvement. Economic Impact survey results indicate that modular construction would enhance job growth (mean = 4.17) and housing quality (mean = 4.19), and foster innovation (mean = 4.22) when adequately supported by local resources.

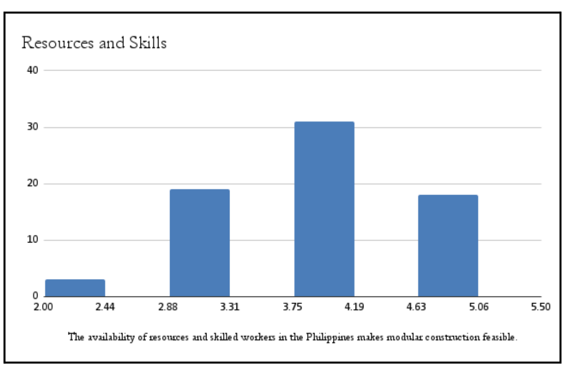


Fig. 5. Histogram of Resource Availability of MC

Fig. 5 highlights the survey data, demonstrating that participants deemed modular construction more efficient in terms of cost (4.03) and sustainability (4.23). At the same time, they found it suitable for accelerating project timelines (4.14). The participants expressed that modular building method provides better advantageous features than potential drawbacks (4.03). Respondents expressed that traditional construction excelled in producing complex designs rather than modular construction (3.45). These findings indicate that although modular construction has cost-effective and environmentally friendly alternatives, such as its reliance on precast reinforced concrete, structural steel, and structural insulated panelling, it is possible to meet expected scepticism about adaptability and structural stability in large projects.

3.4 Key Determinants Influencing Modular Construction Adoption

Applying TPB to the AHP model results in prioritizing external factors affecting awareness about modular construction. The importance-ranking system in the Pairwise Comparison Matrix demonstrates how industry experience matches with media influence academic exposure and shows project timelines, risk perception, and willingness to adopt as main factors contributing to positive perceptions. Academic exposure and media influence, together with industry experience, enabled researchers to determine external factors using the Saaty Analytic Hierarchy Process (AHP), which evaluated views on modular construction. **Table 1** shows the results of the pairwise comparison matrix and the corresponding weights assigned to each factor.

	Familia–rity	Environmental Benefits	Innova–tion	Cost-Effectiveness	Project Timelines	Structural Durability	Mentor Support	Enginne-ring Community	Peer Acceptance	Implem–entation	Resources & Skills	Future Capability
Familiarity	1	1/3	1/3	1/3	1/5	1	1	1/3	1/3	1	1/2	1/2
Environmental Benefits	3	1	1	1/2	1/3	2	2	1	1	2	1	1
Innovation	3	1	1	1/2	1/3	2	2	1	1	2	1	1
Cost-Effectiveness	3	2	2	1	1/2	3	3	2	2	3	2	2
Project Timelines	5	3	3	2	1	5	5	3	3	5	4	3
Structural Durability	1	1/2	1/2	1/3	1/5	1	1	1/2	1/2	1	1	1/2
Mentor Support	1	1/2	1/2	1/3	1/5	1	1	1/2	1/2	1	1	1/2
Enginnering Community	3	1	1	1/2	1/3	2	2	1	1	2	1	1
Peer Acceptance	3	1	1	1/2	1/3	2	2	1	1	2	1	1
Implementation	1	1/2	1/2	1/3	1/5	1	1	1/2	1/2	1	1	1/2
Resources & Skills	2	1	1	1/2	1/4	1	1	1	1	1	1	1
Future Capability	2	1	1	1/2	1/3	2	2	1	1	2	1	1
Risk Perception	4	2	2	1	1/2	3	3	2	2	3	2	2
Cultural Acceptance	3	1	1	1/2	1/3	2	2	1	1	2	1	1
Willingnes to adopt	5	3	3	1	1/2	4	4	3	3	4	3	3

Table 1. Saaty AHP Pairwise Comparison Matrix

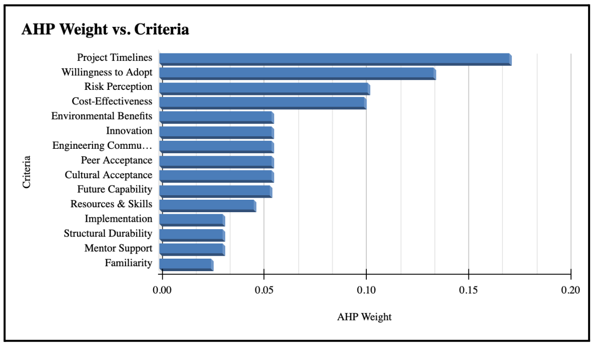


Figure 6. Bar Chart of Comparison of Key Influences on MC

The results from the **AHP analysis** demonstrate that **project timelines represent the most significant factor** because efficiency is a central factor in the acceptance of modular construction, as shown in Figure 6. Different factors, such as **Willingness to Adopt, Risk Perception, and Cost-Effectiveness** follow Project Timelines in importance while demonstrating the **need for industry trust and financial viability. Sustainability,** together with **Professional Recognition,** maintains an intermediate position according to the results of the AHP analysis, while **Time Efficiency** stands as the most **dominant** factor. The adoption factors of **Peer and Cultural Acceptance, as well as Familiarity, Mentor Support, and Structural Durability,** possess **lower** impact rates because time efficiency, along with risk and cost, play a more significant role than social perceptions in adopting modular construction.

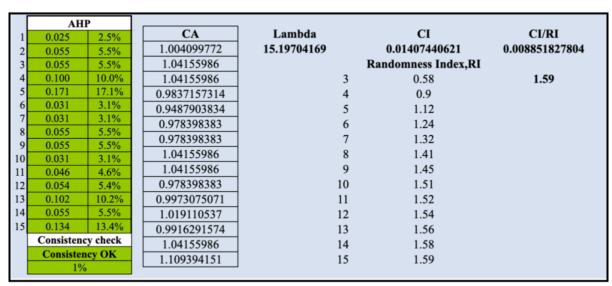
Academic education about modular construction needs strengthening, and credible media coverage is essential to fill industry knowledge gaps. Practical exposure through internships, site visits, and project-based learning significantly influences positive perspectives on modular construction.

Table 2 presents the AHP ranking of key determinants based on stakeholder preferences, providing a structured comparison of factors influencing modular construction adoption. It places the highest project priority on deliverables concerning time and cost-effectiveness, thus emphasizing in the industry the outcome of faster and cheaper construction. Meanwhile, risk perception and structural durability entail fears about the reliability and long-term performance of modular constructions.

Table 2. AHP Ranking of Key Determinants in MC

Factor	AHP Weight	Description
Timeline	17.1%	Impact on speed.
Cost-Effectiveness	10.0%	Financial benefits.
Risk Perception	10.2%	Concerns about drawbacks.
Engr. Community	5.5%	Construction perceptions.
Cultural Norms	5.5%	Social influence.
Resource & Skills	4.6%	Material/labor availability.
Mentor Support	3.1%	Influence of experts.
Durability	3.1%	Structural integrity views.
Feasibility	3.1%	Assessing approaches.

The studied data produced 0.00885**, as shown in Fig. 7. The Consistency Ratio** demonstrates proper logical coherence within the structure of the findings. The analyses showed zero inconsistency through a **lambda (λ) value of 15.197,** while the AHP weights reached 0.067.



	AHP		CA
1	0.025	2.5%	1.004099772
2	0.055	5.5%	1.04155986
3	0.055	5.5%	1.04155986
4	0.100	10.0%	0.9837157314
5	0.171	17.1%	0.9487903834
6	0.031	3.1%	0.978398383
7	0.031	3.1%	0.978398383
8	0.055	5.5%	1.04155986
9	0.055	5.5%	1.04155986
10	0.031	3.1%	0.978398383
11	0.046	4.6%	0.9973075071
12	0.054	5.4%	1.019110537
13	0.102	10.2%	0.9916291574
14	0.055	5.5%	1.04155986
15	0.134	13.4%	1.109394151
	Consistency check		
	Consistency OK		
	1%		

Lambda	CI	CI/RI
15.19704169	0.01407440621	0.008851827804

	Randomness Index,RI	
3	0.58	1.59
4	0.9	
5	1.12	
6	1.24	
7	1.32	
8	1.41	
9	1.45	
10	1.51	
11	1.52	
12	1.54	
13	1.56	
14	1.58	
15	1.59	

Figure 7. Consistency Check Results from AHP Analysis

3.5 Analysis of Interview Insights

Construction professionals working in Bulacan provided different viewpoints about modular construction (MC) following their interviews. The experts understand MC's strength in increasing building efficiency while lowering waste and improving sustainability. However, they note the significant challenges related to the initial expense and minimal supplier availability, along with difficulties finding trained workers. Building professionals consider MC most appropriate for big repetitive projects yet remain uncertain about its design versatility and structural strength. The professionals recommend establishing favorable government policies, industry-wide educational programs, and case studies to prove the long-term sustainability of modular construction, which would improve academic outcomes. Professional opinions indicate encouraging prospects for MC to gain attention through well-directed support together with financial incentives while expanding material access and skilled workforce development.

The research data from conducted interviews shows how the practical usage of MC breaks away from established theoretical benefits. All experts recognize that modular construction speeds up projects and reduces environmental impact, but economic barriers and logistical challenges prevent its general adoption. The development of MC requires government-led incentives and material industry enhancements to overcome its adoption barriers. A broader understanding of MC advantages between clients and laborers could enhance their view toward MC in turn increases demand. The success of MC implementation in Bulacan requires a joint effort between state institutions and private capital investment, which includes qualified workforce development for optimal deployment of this sustainable construction solution.

3.6 Cross-Analysis of Survey and Interview

Research data acquired from surveys and interviews concur with MC adoption views, yet demonstrate distinct interpretations between survey and interview groups. Both groups identified awareness gaps, higher upfront costs, and workforce skill shortages as key barriers while agreeing on MC's advantages in speed, sustainability, and reduced project delays. The interview participants emphasized longer-term cost efficiencies and regulatory challenges as essential barriers, although survey respondents identified code-related awareness problems and initial expenditure needs. The building of these gaps requires specific approaches that combine educational publicity to merge public comprehension with specialist understanding, employee skill development courses, and modifications to existing policies to handle both regulatory and cost-related components. By addressing these areas, stakeholders can foster broader acceptance and leverage MC's full potential in sustainable construction.

3.7 Discussion of Key Trends and Implications

The study shows that MC presents significant benefits yet faces ongoing obstacles because of expensive setup fees, supply chain delivery issues, and local preference for traditional methods, which students, experts, and workers in the Bulacan area support. A comprehensive strategy must be developed to address three main barriers against adoption by combining knowledge-based educational programs with financial assistance and supply chain development for better local market access. The environmental advantages of MC match national objectives regarding sustainable urbanization, positioning this innovation as a practical building method. Strong policies combined with industrial training programs and market innovations could transform Philippine construction through MC technology, driving sustainable efficiency across the sector.

4. CONCLUSIONS

The study demonstrated that modular construction presents extraordinary potential benefits to the Philippine construction market, especially regarding developments in Bulacan. Modular construction offers essential advantages to builders through swift construction times, better quality assurance, environmental sustainability, and waste reduction capabilities, making it appropriate for significant and repetitive building developments such as establishments for housing and education. The general adoption of modular construction is restricted by high investment expenses, the scarcity of local suppliers, and minimal public knowledge. There is also resistance from clients and workers who are more comfortable with traditional methods. Data from descriptive statistics, together with expert testimonies, confirmed that people firmly base their readiness to use modular construction on both perceived control and how others behave.

The Analytical Hierarchy Process (AHP) confirmed these findings and identified financial restrictions, supply chain problems, and training deficiencies as major practical obstacles. Insights from experts indicate positive views about MC but emphasize that wider deployment depends on the fusion between public awareness programs, technical training, and government regulatory backing. Many clients prioritized their own choices and time-tested norms above the technical advantages, highlighting the significance of more substantial promotional efforts. To enhance the successful adoption of modular construction as well as build up local supply chains and technical capacity, it is important to address the issues regarding key materials, namely precast reinforced concrete, structural steel, timber, and structural insulated panels. Collectively, the analysis suggests that MC should compete with conventional methods through supply chain improvements, financial incentives, and skilled employees.

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