Modular Construction Development Constraints in Chongqing: A Fuzzy AHP Framework

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Abstract. Modular construction has emerged as an innovative solution in the building industry, offering substantial potential for enhanced efficiency, cost reduction, and sustainable building practices. However, its development in Chongqing faces several unique challenges. This paper seeks to identify and analyze the key constraints that hinder the widespread adoption of modular construction in the region. Through a comprehensive review of the local construction environment, including regulatory frameworks, material supply chains, labor forces, and technological limitations, the study highlights critical barriers such as insufficient industry standards, a shortage of skilled labor, and logistical challenges. Utilizing a qualitative approach combined with case studies, this research provides a clearer understanding of the specific obstacles faced by the construction industry in Chongqing. The findings aim to provide valuable insights for policymakers, construction managers, and stakeholders, offering guidance on how to address these constraints and promote the growth of modular construction in the region.

Keywords: Modular construction; Fuzzy AHP; Chongqing; sustainable development; barriers.

1 Introduction

Modular construction (MC) is an emerging solution in the building industry, offering benefits like reduced construction time, minimized waste, and improved quality control. Prefabricated modules are built in controlled factory settings and assembled on-site, making this method more sustainable compared to traditional construction. Its environmental advantages—such as energy efficiency, waste reduction, and the potential for reuse—align with global sustainability goals [1]. However, despite its benefits, MC faces challenges, particularly in developing regions like Chongqing, China, where factors like high initial costs, skilled labor shortages, and logistical barriers hinder its adoption.

In China, the government has actively supported MC as part of its green building strategy, encouraging its use in public housing, schools, and healthcare facilities[2].

However, the slow pace of widespread adoption highlights the need for targeted solutions to overcome key constraints such as unclear design standards, cost concerns, and a lack of technological expertise [3]. This research seeks to identify and prioritize these barriers using a fuzzy Analytic Hierarchy Process (AHP) framework, providing valuable insights for stakeholders in Chongqing and offering recommendations to promote sustainable urban development through MC.

2   Literature Review

2.1   Overview of Modular Construction

Modular construction involves prefabricating building components in controlled factory environments, which are then transported and assembled on-site. This method ensures high quality, efficiency, and sustainability through standardized production, waste reduction, and shortened project timelines [1,4]. It is highly flexible, cost-effective, and enhances safety by minimizing on-site risks[5,6] . However, challenges such as high initial costs, transportation logistics, and regional standardization issues persist[2]. Despite these, modular construction is increasingly seen as a sustainable, scalable alternative to traditional methods.

Globally, modular construction has gained momentum in addressing housing shortages and urbanization challenges. In countries like Sweden, around 80% of detached houses use modular components, reflecting the integration of industrialized processes into construction [4,10]. Japan employs advanced modular systems using robotics and automation to produce high-quality modules [1]. These trends emphasize the global shift toward modular methods to tackle labor shortages, rising costs, and environmental concerns. The adoption of Building Information Modeling (BIM) has enhanced modular construction by improving design precision, coordination, and sustainability integration [7].

In China, modular construction aligns with the government's goals for green urbanization. Policies introduced by the Ministry of Housing and Urban-Rural Development (MOHURD) aim for 30% prefabricated building adoption by 2030[2] . Despite progress in metropolitan areas, challenges such as a lack of clear design standards and high upfront costs hinder broader adoption, especially in cities like Chongqing [5,17].

2.2   Challenges in Modular Construction

Several barriers hinder the widespread adoption of modular construction, particularly in Chongqing, which can be categorized into technical, economic, social, environmental, safety, and organizational factors.

- Technical Barriers: A significant challenge is the lack of standardized design, which creates inefficiencies and difficulties in integrating modular components with traditional systems[18]. Furthermore, there is a shortage of skilled labor in areas such as factory production, transportation, and assembly [3].

- Economic Barriers: High initial investments for production facilities and equipment deter adoption, particularly in regions where traditional methods dominate [1]. Moreover, conventional methods are often perceived as lower-risk despite the long-term savings offered by modular construction[8] .
- Social Barriers: Modular construction is often viewed as low-quality or temporary housing, limiting its public acceptance [3]. Resistance to change is particularly strong in regions like Chongqing, where traditional methods are entrenched [2].
- Environmental Barriers: While modular construction reduces waste, the carbon footprint from transporting modules and the sustainability of materials remain concerns[10] .
- Safety Barriers: Safety risks during transportation and on-site assembly are significant, particularly when large modules are moved through congested or poorly developed areas [6].
- Organizational Barriers: Effective coordination between stakeholders is crucial, and poor organizational management can lead to delays, quality issues, and higher costs [17].

2.3   Key Gaps in Research

There are several gaps in existing research on modular construction:

Limited Regional Case Studies: Most studies focus on major cities, leaving regions like Chongqing with unique challenges underexplored[8].

Long-Term Performance: There is a lack of research on the long-term sustainability and performance of modular buildings[1].

Technological Integration: The role of advanced technologies like BIM, robotics, and automation in overcoming barriers remains under-researched [2].

Government Policies: More research is needed to assess the effectiveness of policies and explore how they can be enhanced to incentivize modular construction adoption [9].

2.4   Application of Fuzzy AHP in Construction

Fuzzy AHP is a decision-making tool used to address uncertainty and subjectivity in construction. It integrates fuzzy logic with AHP, enabling decision-makers to evaluate factors like cost, risk, and technology [9]. In modular construction, it helps prioritize constraints, assess risks, and optimize resources. For Chongqing, Fuzzy AHP can identify and prioritize challenges such as cost, public perception, and technical difficulties, guiding targeted investments in infrastructure and awareness campaigns.

Fuzzy AHP's future potential lies in its integration with BIM and AI, enhancing decision-making and predictive modeling for better project outcomes.

3   Methodology

3.1   Research Framework

This study uses the Fuzzy Analytic Hierarchy Process (FAHP) to identify and prioritize key constraints in the development of modular construction. The methodology consists of several key phases, including data collection, model construction, and result analysis.

3.1.1 Research Framework.

The research framework integrates Fuzzy AHP with expert opinions to evaluate the constraints. It begins with identifying key constraints, followed by data collection through expert surveys. The analysis is conducted using Fuzzy AHP to calculate weights and prioritize the identified constraints.

A rigorous evaluation of modular construction constraints requires a well-defined set of criteria. To establish these criteria, the study integrates insights from **existing literature, industry standards, and expert consultations**. The following section outlines the selection process, ensuring that the identified constraints are both theoretically sound and practically relevant.

3.1.2 Criteria and Sub-Criteria Selection.

The selection of criteria and sub-criteria for this study was based on a comprehensive review of literature, industry standards, government regulations, and expert consultations to ensure the robustness and applicability of the identified constraints. The process involved three key steps:

- Literature Review: Previous studies on modular construction constraints[2,3]were analyzed to identify critical barriers such as economic feasibility, regulatory challenges, supply chain inefficiencies, and technical limitations. These studies provided a theoretical foundation for the classification of constraints and helped establish their relevance to modular construction adoption.
- Industry Standards and Government Reports: Reports from China's Ministry of Housing and Urban-Rural Development[11]and Singapore's Building and Construction Authority [12] were reviewed to supplement the selection of criteria. These documents emphasized the importance of policy incentives, material availability, construction safety standards, and workforce training, which were incorporated into the evaluation framework.
- Expert Consultation: To further refine the selection of criteria and ensure their relevance to the local context, 11 experts from academia, construction firms, and regulatory bodies were consulted. These experts contributed insights on region-specific challenges in Chongqing's modular construction sector, validating the classification of constraints and their relative importance.

Based on these sources, six primary constraint categories were established: economic, technical, safety, organizational, supply chain, and external factors, with corre-

sponding sub-criteria detailed in Table 1. This structured approach ensured that the selection of constraints was grounded in empirical research, industry best practices, and expert judgment.

Having established a structured and well-supported set of constraints, the next phase of the study focuses on quantifying their relative importance. This is achieved through expert evaluations, which form the foundation for the FAHP model. The following section details the data collection process, including expert selection and survey methodology.

3.1.3 Data Collection.

Data was collected through expert interviews and surveys. The expert panel was carefully selected to ensure diversity and representativeness. It included senior engineers with hands-on modular construction experience, technical specialists in prefabrication technologies, academic researchers focusing on construction innovation, and policymakers involved in industry regulations. Their collective expertise provided a balanced perspective on the constraints facing modular construction in Chongqing.

These experts provided valuable insights on the constraints impacting modular construction, which were quantified using a questionnaire. A total of 11 experts participated in the survey, evaluating various factors affecting the development of modular construction in the context of Chongqing.

3.1.4 FAHP Model Implementation.

The FAHP model was developed through the following steps:

- Hierarchy Construction: A hierarchical model was created for the key constraints, with the goal layer (modular construction development), criterion layers (economic, technical, safety, etc.), and sub-criterion layers identified.
- Fuzzy Judgment Matrix Construction: Experts used a 1-9 scale to perform pairwise comparisons between the factors, resulting in a fuzzy judgment matrix.
- Consistency Check: The consistency of the judgment matrix was tested using the consistency ratio (CI). A CI value below 0.1 indicates a consistent matrix.
- Weight Calculation and Prioritization: The maximum eigenvalue and eigenvector of the matrix were calculated to determine the weights of each constraint. The priorities of constraints were then derived based on these weights.

3.1.5 Tools and Software.

The analysis was conducted using Excel for fuzzy AHP calculations and data organization. Excel was instrumental in performing fuzzy calculations and managing collected data, as well as generating graphical representations of the results.

3.1.6 Result Validation and Hypothesis Testing.

The results were validated through sensitivity analysis to test the impact of varying expert scores. Additionally, comparisons were made with alternative methods, such as principal component analysis (PCA), to ensure the robustness of the findings.

3.2   Conceptual Model for Identifying Constraints

Table 1 provides a concise summary of the Comprehensive Evaluation Indicators for Modular Construction. The conceptual model identifies the key constraints affecting the development of modular construction in Chongqing, categorizing them into six primary dimensions: Economic, Safety, Organizational, Supply Chain, Technical, and External. Each dimension includes specific factors contributing to the limitations in the modular construction process.

Table 1. Comprehensive Evaluation Indicators for Modular Construction

Criteria Level	Index	sub-criteria	Index
Economic Constraints	B1	Fluctuations in the prices of labor, materials, and machinery	C1
		Large deviation in cost estimation	C2
		Inflation	C3
Safety Constraints	B2	Personnel Factors	C4
		Mechanical Factors	C5
		Material Factors	C6
		Construction Method Factors	C7
		Environmental Factors	C8
Organizational Constraints	B3	Unequal distribution of benefits	C9
		Irregular process coordination	C10
		Information asymmetry among stakeholders	C11
Supply Chain Constraints	B4	Unstable supply	C12
		Unstable quality	C13
		Price factors	C14
		Insufficient collaboration	C15
Technical Constraints	B5	Low level of integration	C16
		Incomplete modular system	C17
		Immature technological system	C18
		Key component quality control issues	C19
External Constraints	B6	Incomplete policy support and incentive measures	C20
		nadequate supporting construction laws and regulations	C21
		Harsh natural environment	C22

3.3   Fuzzy AHP-Based Analytical Framework

1) Define an n-Dimensional Square Matrix R:

$$R = (r_{ij})_{n \times n} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{bmatrix} \tag{1}$$

- If the matrix R satisfies $0 \le r_{ij} \le 1$, (i, j = 1, 2, ..., n), then R is a fuzzy matrix;
- If the matrix R satisfies condition 1 and rij + rji = 1 for all i and j , then R is a fuzzy complementary matrix;
- If the matrix R satisfies conditions 1 and 2, and r_{ii}=0.5, (i=1, 2, $\cdots$, n); r_{ij}=r_{ik}-r_{jk}+0.5, (i, j, k=1, 2, $\cdots$, n), as it was not provided in your original query.
- Then R is referred to as a fuzzy consistent matrix.

2) Construction of the Fuzzy Analytic Hierarchy Scoring Matrix
Using the 0.1 to 0.9 scaling method mentioned above, each evaluation factor is compared in pairs to obtain the fuzzy analytic hierarchy scoring matrix A:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{2}$$

3) Sum the rows of matrix A

$$a_i = \sum_{k=1}^{n} ak, (a_i, k = 1, 2 \cdots n) \tag{3}$$

4) Calculate the weight vector Wi for each factor.

$$w_i = \frac{1}{n} - \frac{1}{2\alpha} + \frac{a_i}{n\alpha} \tag{4}$$

$$W_1 = \begin{bmatrix} w_1 w_2 \cdots w_n \end{bmatrix}^T \tag{5}$$

In the formula, set

$$\alpha = \frac{n-1}{2} \tag{6}$$

5) Consistency CI Test
Construct the Weight Matrix W

$$w_{ij} = \alpha(w_i - w_j) + 0.5 \tag{7}$$

$$W = \begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1n} \\ w_{21} & w_{22} & \cdots & w_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ w_{n1} & w_{n2} & \cdots & w_{nn} \end{bmatrix} \qquad (8)$$

$$CI(A,W) = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} |w_{ij} - a_{ij}|}{n^2} \qquad (9)$$

The smaller the CI value, the better the consistency. Generally, if CI<0.1, it is considered to meet the consistency requirement.

3.4   Validation Techniques

The framework will provide a prioritized list of constraints specific to Chongqing, along with actionable insights. These findings will help guide policymakers and industry stakeholders in addressing the most urgent issues, thereby facilitating the development of modular construction in the region.

By integrating a conceptual model with the analytical rigor of Fuzzy AHP, this research framework ensures a thorough and context-specific evaluation of the constraints impacting modular construction.

4   Results and Discussion

4.1   Questionnaire Design and Reliability Analysis

To ensure the validity and reliability of the collected data, a structured questionnaire was developed based on the refined constraints in modular construction. The questionnaire was distributed to 11 industry experts from diverse professional backgrounds, ensuring a high level of representativeness in the responses. Among the experts:

- 4 were from academia, with expertise in modular construction research and education.
- 2 specialized in technology, contributing insights into technical challenges and innovations in modular construction.
- 2 had an economic focus, including one from an accounting firm, providing perspectives on financial constraints and cost analysis.
- 2 were from architectural design institutes, offering expertise on design standardization and regulatory frameworks.
- The remaining experts were senior management professionals from construction firms, contributing firsthand knowledge of practical implementation challenges in modular construction projects.

To enhance the accuracy and efficiency of data collection, the questionnaire underwent a pre-test phase, during which experts provided valuable feedback. This led to refinements in question clarity and structure, as well as the adoption of "Changsha Ranxing IT Ltd" for online survey distribution. These optimizations ensured that the questionnaire effectively captured the critical constraints affecting modular construction in Chongqing.

The reliability of the survey data was evaluated using Cronbach's Alpha. The overall Cronbach's Alpha coefficient was found to be 0.978, indicating high reliability of the data. Further, the CITC (Corrected Item-Total Correlation) values were all above 0.4, confirming that the items in the questionnaire are strongly correlated. However, it was observed that removing certain factors, such as Safety Factors, Labor/Material Price Fluctuations, Construction Method Factors, and Environmental Factors, would increase the reliability coefficient, suggesting potential adjustments to these factors.

This analysis confirms that the data collected is reliable and supports the subsequent analysis of the key constraints affecting modular construction in Chongqing.

4.2   Results

In this section, the key constraints hindering the development and adoption of modular construction in Chongqing are presented and analyzed. These constraints were identified and prioritized using the Fuzzy Analytic Hierarchy Process (FAHP) model, incorporating both expert opinions and objective data. The constraints are categorized into economic, safety, organizational, supply chain, technical, and external factors, and their relative importance is discussed below.

4.2.1 Economic Constraints.

Economic factors were found to be the most significant barriers to the widespread adoption of modular construction in Chongqing. Among these, fluctuations in labor, material, and machinery prices were identified as the most critical constraint, with a global weight of 0.0592, ranking 1st. These fluctuations have a major impact on the overall cost of modular construction projects, making it difficult for stakeholders to manage budgets effectively and predict costs.

Following closely are cost estimation deviations and inflation, both with a global weight of 0.056, ranked 5th and 6th, respectively. These economic constraints further exacerbate the financial risks associated with modular construction. Despite the long-term savings offered by modular construction in terms of time and material waste reduction, the initial high costs and financial uncertainties remain significant obstacles.

4.2.2 Safety Constraints.

While safety factors are crucial, they were ranked lower in comparison to economic and organizational constraints. Among the safety factors, personnel factors received the highest weight of 0.0318, ranked 20th, followed by mechanical factors at 0.0323, ranked 19th. These findings suggest that although safety issues are present, they are

less critical in comparison to the economic and organizational factors affecting the adoption of modular construction in Chongqing.

The environmental and construction method factors ranked 21st and 22nd, respectively, indicating that safety concerns, such as the risks involved in transporting and assembling large modular components, are important but not as pressing as other factors in this specific context.

4.2.3 Organizational Constraints.

Organizational factors, such as unequal distribution of benefits and poor process coordination, were identified as significant barriers. Poor process coordination received the highest global weight of 0.0578, ranking 3rd. This emphasizes the need for better communication and collaboration among stakeholders, including manufacturers, contractors, and local authorities, to ensure smoother implementation of modular construction projects.

Unequal distribution of benefits and information asymmetry were ranked 8th and 9th, respectively, further highlighting that organizational inefficiencies are key obstacles to the successful implementation of modular construction in Chongqing.

4.2.4 Supply Chain Constraints.

Supply chain-related constraints, such as unstable supply and insufficient collaboration, were identified as moderate barriers. Among these, collaboration was rated the highest, with a global weight of 0.0435, ranking 10th. This indicates that while collaboration within the supply chain is important, it is not as urgent as addressing economic and organizational factors.

Quality and price factors were ranked 13th and 14th, respectively. While these challenges are relevant, they do not have as significant an impact on the development of modular construction in Chongqing compared to economic and organizational constraints.

4.2.5 Technical Constraints.

Technical barriers, such as low integration levels, incomplete modular systems, and immature technology, were ranked lower compared to other factors. Low integration levels and modular system imperfections received weights of 0.0402 and 0.0423, ranking 16th and 12th, respectively. Although these technical challenges need to be addressed, they are considered less critical than the economic and organizational constraints currently hindering the adoption of modular construction in Chongqing.

4.2.6 External Constraints.

External factors, including insufficient policy support, lack of supportive construction laws, and harsh natural environments, were also identified as significant constraints. Among these, insufficient policy support emerged as the most critical factor, ranked 2nd, with a global weight of 0.0582, followed closely by lack of supportive construction laws at 4th. Harsh natural environments were ranked 7th, indicating that

while environmental challenges exist, they are less significant than policy-related factors in limiting modular construction development in Chongqing.

4.3   Discussion of Key Findings

The findings indicate that economic factors, particularly fluctuations in labor, material, and machinery prices, are the most significant barriers to modular construction adoption in Chongqing. These economic constraints, compounded by the high initial investment required for modular production facilities and specialized equipment, make it challenging for stakeholders to adopt modular construction methods.

External factors, such as insufficient policy support and lack of supportive construction laws, are critical to the successful adoption of modular construction in Chongqing. Without comprehensive policy support and regulatory frameworks, it is difficult to foster widespread adoption of this innovative construction method.

Organizational inefficiencies, particularly poor process coordination, were also found to be major barriers. Improving coordination among stakeholders is essential for the smooth execution of modular construction projects.

While safety and technical factors were considered, they were ranked lower in comparison to economic and organizational factors. This suggests that while technical improvements and safety measures are necessary, the primary challenges in Chongqing lie in the economic, organizational, and policy areas.

These findings highlight that economic, organizational, and regulatory constraints are the primary challenges for modular construction in Chongqing.

Despite ongoing efforts, the widespread adoption of modular construction remains limited due to the absence of strong financial incentives, standardized regulatory frameworks, and well-integrated supply chain management.

To explore how these challenges can be addressed, it is useful to examine other cities that have successfully implemented modular construction policies.

By analyzing the experiences of Singapore and Shanghai, we can identify key strategies that could be adapted to Chongqing's context.

The following section provides a comparative analysis of these two cities, offering insights into how government policies, financial mechanisms, and industry innovations have facilitated modular construction adoption.

4.4   Comparative Analysis with Other Cities

To accelerate modular construction adoption in Chongqing, lessons from Singapore and Shanghai provide valuable insights. Both cities have successfully implemented policies and strategies that could be adapted to Chongqing's context.

Singapore follows a government-driven approach, where at least 30% of all public projects must use Prefabricated Prefinished Volumetric Construction (PPVC) [11]. Financial incentives under the Buildability Framework subsidize developers adopting modular methods, reducing initial investment costs [15]. Additionally, Singapore mandates BIM adoption for public projects and offers government-funded training programs to ensure a skilled workforce[13,14] . For Chongqing, enforcing modular con-

struction in public projects, providing financial incentives, and promoting BIM training could drive industry-wide transformation.

Shanghai takes an industry-led approach, supported by standardization, large-scale pilot projects, and public-private partnerships (PPP). The city established detailed prefabrication standards to improve efficiency [16]. In Lingang New Area, more than 50% of new residential developments use modular construction, demonstrating cost and time savings[17]. Government-backed pilot projects, such as the Qingpu Prefabrication Demonstration, showed modular construction could reduce waste by 50% and shorten construction timelines by 30% [2]. For Chongqing, establishing clear modular construction codes, launching pilot projects, and fostering government-industry collaboration would enhance adoption.

Comparing these cities shows that strong policies, financial support, and industry collaboration are key drivers of modular construction success. Singapore's top-down regulatory enforcement and Shanghai's industry-driven innovation highlight different but effective models. Chongqing can integrate both approaches by enforcing modular standards in public projects, offering subsidies and tax incentives, and leveraging PPP models to enhance private sector participation.

By adopting these strategies, Chongqing can overcome existing barriers and drive modular construction growth, contributing to a more sustainable urban development model.

4.5   Policy Recommendations and Practical Strategies

To accelerate the adoption of modular construction in Chongqing, this section outlines key policy recommendations and practical strategies aimed at addressing economic, regulatory, and technical challenges.

4.5.1 Strengthening Policy and Financial Support.

- Targeted Incentives: The government should offer tax reductions, financial subsidies, and low-interest loans to modular construction enterprises to ease initial investment burdens. Public projects, such as affordable housing and hospitals, should prioritize modular construction to set industry benchmarks.
- Regulatory Optimization: Establish clear legal frameworks for modular construction, including standardized design codes, production criteria, and approval processes to streamline project implementation and improve compliance.
- Skilled Workforce Development: Introduce modular construction courses in universities and vocational training programs. Government-backed training initiatives should upskill workers in prefabrication, BIM technology, and automated manufacturing[13].

4.5.2 Advancing Industry Efficiency and Innovation.

- Supply Chain Coordination: Encourage localized production of modular components to reduce logistics costs and enhance supply chain stability. Strengthening partnerships between manufacturers and construction firms can improve efficiency.
- Technology Integration: Promote the use of BIM, AI, and automation to enhance precision in design, manufacturing, and on-site assembly. Financial incentives should be offered for companies adopting smart construction technologies.
- Quality Assurance and Standardization: Implement industry-wide quality control protocols to ensure modular components meet uniform safety and durability standards, reducing inconsistencies across different manufacturers.

4.5.3 Increasing Public Awareness and Market Adoption.

- Demonstration Projects: Construct high-quality modular housing and commercial buildings as pilot projects to showcase feasibility and benefits, improving public and industry perception.
- Industry Collaboration and Knowledge Sharing: Establish a regional modular construction alliance to facilitate research, data sharing, and policy coordination between government, academia, and private enterprises.
- Public Education Campaigns: Conduct awareness programs through media and trade fairs to highlight the advantages of modular construction in cost, efficiency, and sustainability.

By implementing these strategies, Chongqing can accelerate modular construction adoption, enhance industry competitiveness, and drive sustainable urban development.

4.6   Future Research Directions

As modular construction continues to evolve, future research should focus on:

- Smart and Sustainable Modular Construction: Exploring how smart technology and green materials can further enhance modular construction efficiency and environmental impact.
- Comparative Studies with Other Cities: Investigating the successes of modular construction in cities such as Singapore and New York to extract valuable insights for Chongqing.
- Long-Term Performance and Market Adaptability: Analyzing the life-cycle performance and cost-effectiveness of modular buildings to strengthen the business case for wider adoption.

5   Conclusions

This study has identified and analyzed the key constraints hindering the development and adoption of modular construction in Chongqing. Using the Fuzzy Analytic Hier-

archy Process (FAHP) framework, several critical barriers were identified and prioritized, categorized into economic, safety, organizational, supply chain, technical, and external factors. The findings provide valuable insights that can guide stakeholders in addressing these barriers to promote the growth of modular construction in the region.

5.1   Key Findings

The results indicate that economic factors, particularly fluctuations in labor, material, and machinery prices, are the most significant obstacles to the widespread adoption of modular construction in Chongqing. These economic constraints are further compounded by high initial costs, cost estimation deviations, and inflation, making it difficult for stakeholders to justify the financial investment required for modular construction projects.

External factors, such as insufficient policy support and lack of supportive construction laws, followed closely behind economic constraints. These factors are critical for creating a conducive environment for modular construction to thrive. The lack of regulatory frameworks and incentives hinders the full adoption of modular methods and delays the shift from traditional construction methods.

Organizational inefficiencies, especially poor process coordination and unequal distribution of benefits among stakeholders, were also found to be major barriers. Improving communication and collaboration among manufacturers, contractors, and local authorities is essential for overcoming these organizational challenges and ensuring the successful implementation of modular construction projects.

While safety and technical barriers are important, their impact is less significant than the economic and organizational constraints. Safety concerns, such as risks during the transportation and assembly of large modular components, and technical issues, like low integration levels and incomplete modular systems, remain challenges but are not as pressing as the financial and organizational factors.

5.2   Recommendations

To address the key constraints identified in this study, several strategies are recommended:

Economic Stabilization: Efforts should focus on stabilizing labor, material, and machinery prices, as well as improving the accuracy of cost estimation. Government interventions, such as financial incentives and subsidies, could help mitigate the high initial costs and promote modular construction.

Strengthening Policy Support: Policymakers should develop clear and comprehensive policies that encourage modular construction. This includes providing financial support, creating regulatory frameworks to promote modular designs, and offering incentives to reduce the barriers faced by contractors.

Enhancing Organizational Coordination: Improving coordination between stakeholders is essential for smooth project execution. By ensuring better communication and collaboration across the supply chain, organizational inefficiencies can be minimized, thus ensuring successful project outcomes.

Addressing Safety and Technical Challenges: While less critical, safety measures should be improved, particularly during transportation and assembly phases. Additionally, continued investment in research and development to enhance the integration of modular systems and technology will improve the scalability and compatibility of modular construction.

5.3   Future Research Directions

While this study provides a comprehensive understanding of the key constraints, there are still areas that require further investigation. Future research could focus on the long-term sustainability and performance of modular buildings, examining how these structures perform over time. Additionally, the role of advanced technologies such as robotics, automation, and Building Information Modeling (BIM) in overcoming technical barriers should be explored to further streamline the modular construction process.

Further regional case studies and comparisons with other cities or countries successfully adopting modular construction could also offer valuable insights into best practices and strategies for overcoming common challenges.

In conclusion, overcoming the barriers to modular construction in Chongqing requires a multi-dimensional approach. Economic stability and strong policy support should be prioritized, as these are the most pressing challenges. Additionally, enhancing organizational coordination, addressing safety concerns, and advancing technical solutions are essential for the successful adoption and implementation of modular construction. By focusing on these strategies, stakeholders in Chongqing can promote the growth of modular construction, contributing to the region's sustainable urban development.

5.4   Limitations and Future Research

While this study successfully applies the Fuzzy AHP (FAHP) methodology to analyze the constraints of modular construction in Chongqing, several limitations should be recognized, providing opportunities for future refinement and research.

5.4.1 Subjectivity in Expert Judgments.

The FAHP model heavily depends on expert evaluations for pairwise comparisons, which may introduce subjectivity and inconsistencies in the weighting process. To enhance the reliability of results, future research could incorporate Delphi method refinements to achieve expert consensus or expand the sample size of experts to improve data robustness.

5.4.2 Limited Integration of Objective Data.

This study primarily relies on qualitative assessments from experts, which may not fully reflect real-world project conditions. To improve accuracy, future research could

integrate FAHP with historical project cost data, performance metrics, and supply chain analytics, enabling a more data-driven approach to constraint prioritization.

5.4.3 Computational Complexity.

As the number of criteria increases, FAHP calculations become more computationally intensive, posing challenges in large-scale applications. Future studies may explore hybrid models that integrate FAHP with machine learning techniques or Multi-Criteria Decision Making (MCDM) methods (e.g., TOPSIS, ELECTRE) to enhance computational efficiency and decision-making precision.

By addressing these limitations, future research can significantly enhance the transparency, objectivity, and applicability of FAHP in modular construction decision-making, ensuring more reliable and data-driven evaluations.

Acknowledgments

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