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Evaluation of Key Factors for Promoting Green Construction Practices Based on a Hybrid Decision-Making Framework: A Case Study on the Renovation of Old Residential Communities in China

Guoshuai Sun [1,2,3], Mingzhu Li [2], Jiuying Dong [4,*], Shuping Wan [5] and Jiao Feng [6,*]

[1] School of Civil Engineering and Architecture, Xinjiang University, Urumqi 830047, China; sungs@lnut.edu.cn
[2] School of Economics and Management, Liaoning University of Technology, Jinzhou 121001, China; lmz19980112@163.com
[3] School of Information Management, Jiangxi University of Finance and Economics, Nanchang 330032, China
[4] School of Science, Shanghai Institute of Technology, Shanghai 201418, China
[5] School of Management, Shanghai University of Engineering Science, Shanghai 201620, China; shupingwan@163.com
[6] School of Maritime Economics and Management, Dalian Maritime University, Dalian 116026, China
* Correspondence: jiuyingdong@126.com (J.D.); jiao_fj@163.com (J.F.)

Abstract: The multi-criteria group decision-making approach, rooted in fuzzy mathematics theory, is employed to address the globally significant issue of green construction in this paper. The construction industry is one of the most prominent contributors to carbon emissions, which is evident throughout the entire supply chain. Meanwhile, the renovation of old residential communities is a large-scale urban construction project in China. In striving to advance the sustainable development of the construction industry and meet decarbonization goals, the attention has shifted towards green construction in the renovation of old residential communities. However, substantial gaps persist in both technical innovation and practical application of green construction. This study aims to identify the factors that influence the popularization and implementation of green construction practices in the renovation of old residential communities. To achieve this, a comprehensive decision-making approach is sought, and these factors are thoroughly investigated. In this paper, we propose a hybrid decision-making framework that incorporates grounded theory, the fuzzy decision-making and trial evaluation laboratory (DEMATEL) method, and the analytic network process (ANP) method. Leveraging triangular fuzzy numbers and other fuzzy mathematical theories, this approach is designed to assess the factors that influence the popularization and implementation of green construction practices, uncovering their interrelationships and mechanisms. The results indicate the comprehensive nature of advancing green construction practices, encompassing the entire supply chain involved in the renovation of old residential communities. Among these factors, social participation and market environment emerge as the most influential. Building upon these conclusions, this paper offers specific recommendations. Ultimately, this study equips the construction industry with both a theoretical foundation and a methodological framework to popularize and implement green construction practices effectively.

Keywords: group decision-making; fuzzy DEMATEL; ANP; factor analyses; renovation of old residential communities; green construction

MSC: 03B52; 03E72; 91B06; 62P30

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1. Introduction

The concept of sustainable development has evolved into a global imperative, encompassing dimensions within economics, society, and the environment [1]. The construction industry assumes a pivotal role in the progress of a nation, particularly in its impact on the environment, which stands as a paramount catalyst for achieving a sustainable future. Construction endeavors yield substantial waste production, necessitate extensive resources and materials, and concurrently make a significant contribution to overall energy consumption [2]. As outlined in the "2021 Global Status Report for Buildings and Construction" by the International Building Organization, carbon emissions attributable to the construction industry constituted 37% in the year 2020. Consequently, the construction industry, akin to other sectors, must align itself with the principles of the green growth policy [3]. Due to the pervasive influence of carbon emissions across the entire supply chain, encompassing procurement, transportation, construction, operation, and even demolition phases, the concept of green construction (GC) has emerged as a recognized, effective, and sustainable paradigm within the domain of the construction industry.

Urban renewal represents the exclusive pathway toward ensuring the survival, progression, and maturation of a city [4]. Currently, China has embarked on a series of urban renewal initiatives, wherein the renovation of old residential communities (RORC) has played a major role. Unlike new construction endeavors, projects focused on the renovation of old residential communities confront challenges such as environmental pollution and interference with the lives of residents. Green construction refers to the adoption of processes and techniques characterized by environmental responsibility and resource efficiency throughout the entire life cycle of a building [5]. The central responsibility for steering the construction industry towards sustainability chiefly resides in the purview of low-carbon governance [6], all while concurrently pursuing the dual goals of economic and ecological considerations [7]. Therefore, to more effectively advance the environmentally conscious growth of the construction industry and achieve decarbonization goals, green construction has garnered global attention within the realm of the construction industry.

The popularization of green construction practices across the entire supply chain facilitates the translation of theoretical findings and practical implementations, thereby contributing to the attainment of success in sustainable development. In China, the renovation of old residential communities has emerged as the main body of the construction industry. The relationship between old and new buildings is one of partnership rather than rivalry. The USA's National Trust for Historic Preservation offers valuable evidence and expertise for the construction and preservation of beautiful and sustainable urban environments. Meeks and Murphy's proposition, centered on the preservation of historic buildings and telling the stories of particular groups, advocates shaping the future of communities in continuity with their past [8]. In contrast, China's renovation projects for old residential communities predominantly aim to enhance the living environment of residents from the perspectives of energy efficiency, safety, and convenience. However, their common goals lie in reducing energy costs, preserving the environment, and fostering urban sustainability. Hence, the exploration of a sustainable development pathway for these communities holds paramount significance in advancing China's green construction endeavors.

As the foremost global carbon emitter, China has made a firm commitment, declaring that "China will strengthen its innovation capacity, adopt more proactive and effective policies and measures, and endeavor to achieve carbon peak by 2030 and carbon neutrality by 2060." [9]. The government assumes a constructive role in the implementation and advancement of green construction practices. In this milieu, the present study seeks to explore the key factors governing the popularization and implementation of green construction practices within the realm of RORC.

In addition to the aforementioned motivation, another pivotal objective is to propose an optimal approach that effectively addresses the gaps and offers a comprehensive and reliable analysis of the key factors exerting influence and their operational mechanisms. This study serves to assist the government in making decisions to promote the implementation of green construction practices in RORC. This study argues that the factors influencing the popularization and implementation of green construction practices in RORC are multifaceted and interactive. Thus, this study proposes a hybrid framework designed to screen these factors and explore their interconnectedness and mechanisms. Judging from our previous investigation, any substantial studies addressing the specific issue of the influencing factors for the popularization and implementation of green construction practices employing the hybrid framework proposed have been not yielded in other papers. The main contributions and innovations of this paper are outlined as follows. Firstly, the research framework of a hybrid approach has been constructed, which can be utilized for the analysis of the influencing factors and their operational mechanisms for those similar phenomena. Notably, a combined weighting method based on an improved game theory framework is provided in this paper. Secondly, the influencing factors governing the popularization and implementation of green construction practices in RORC have been effectively identified through a meticulous screening process. Consequently, the primary challenge of fostering the popularization and implementation can be addressed. Thirdly, causal analyses have been conducted, shedding light on the effectiveness and sensibility of those influencing factors. The study affords the government a referential pathway for the advancement of green construction practices in RORC.

The subsequent sections of this paper are structured as follows: Section 2 delves into the comprehensive review of previous studies. Section 3 introduces the methodological framework. Then, Section 4 encompasses case analysis and the practical application of the hybrid approach. This paper is concluded and policy implications are provided in Section 5. Finally, some limitations are analyzed and further research is suggested in Section 6.

2. Literature Review

This study explores the influencing factors and their operational mechanisms that contribute to the popularization and implementation of green construction practices, with a specific focus on RORC in China, which has garnered relatively limited attention in the existing studies. However, this study addressed a scarcity of studies dedicated to exploring the issue of combining RORC and green construction practices.

Green construction technologies (GCTs) play a pivotal role as catalysts for sustainable development within the construction industry. Regarding the construction modality, the evolution of prefabrication techniques has ushered in the era of prefabricated concrete (PC) structures, propelling the construction industry towards ecological building practices [10]. Notably, Luo et al. [11] conducted a comprehensive review of prefabricated construction policies in China, subsequently presenting optimization recommendations. Turning to construction materials, the utilization of sustainable building materials assumes paramount significance within the realm of green construction practices [12]. Delving deeper, Joyram [13] conducted a meticulous analysis of the application of environmentally conscious construction materials in Mauritius. From the perspective of construction facilities, Lee et al. [14] introduced a green construction hoist that was engineered to diminish its operational energy demands, representing a pragmatic approach to curtailing energy consumption during construction endeavors. Interestingly, building information modeling (BIM) technology has witnessed widespread adoption in green engineering construction and is hailed as an effective approach towards achieving the goal of green construction [15]. Furthermore, some researchers have delved into the ecological indicators for green construction, combining resource conservation and environmental protection [16]. The above-mentioned literature scrutiny of green construction technologies indicates that the swift maturation of technological prowess serves as the bedrock for subsequent popularization and implementation.

Government authorities and construction enterprises have adopted various measures to incentivize the application of green construction technologies. For instance, Najimu et al. [17] proposed a reward and compensation scheme, wherein the government's subsidies and compensation plans have been elucidated. By incorporating the principles of lean management into the construction domain, Valentina et al. [18] posited that the combination of both lean and green construction technologies contributes to enhancing sustainability. Avotra et al. [19] conducted an in-depth analysis of the consequential relationship between corporate social responsibility (CSR) and green construction practices. From a supply chain perspective, their standpoint revolves around the notion that green procurement, an integral component of green construction practices, acts as a robust mediator, bridging corporate social responsibility with the pursuit of sustainable development goals. Exploring construction sites, Wu et al. [20] delved into alternative water-saving measures and emphasized the centrality of water-saving strategies within diverse evaluation frameworks for green construction practices. Subsequently, ten water-saving measures were proposed. However, in Malaysia, Bohari et al. [21] suggested that stakeholder values exerted a positive influence on shaping the environmentally conscious construction procurement practices. From a managerial perspective, Zhang et al. [22] contended that the implementation of effective environmental regulations (ERs) was imperative to foster the adoption of greener technologies. In addition, government incentives, encompassing mechanisms such as taxes and subsidies, have propelled the advancement of green industries [23]. Furthermore, Hwang et al. [24] advocated the development of a comprehensive project management framework tailored to the nuances of green construction practices. The above-mentioned literature analysis on incentive policies indicates that the government and some construction enterprises have the willingness to promote the adoption of green construction practices.

Various factors influencing the popularization of green construction practices have been studied. From a policy perspective, Qi et al. [25] categorized pertinent policies into five distinct domains, encompassing financial, managerial, organizational, societal, and technological aspects. Additionally, Qi et al. [26] unveiled that the primary driving force propelling the adoption of green practices lies in managerial concern, a factor of paramount significance. Nonetheless, when it comes to the incorporation of green techniques, noteworthy correlations emerge between government regulations and business size. Against the backdrop of the burgeoning prefabrication trend, Jiang et al. [27] proposed five pivotal factors: policy, technology, management, market dynamics, and cost considerations. Scrutinizing the impediments to development, Wang et al. [28] conducted an assessment of the principal barriers hindering the widespread acceptance of GCT in China, meticulously identifying and enumerating 21 barriers. Meanwhile, Shi et al. [29] contended that salient obstacles meriting attention encompass supplementary expenditures, heightened time commitments, and the limited accessibility of green suppliers and pertinent information. From an enterprise perspective, Li et al. [30] and Li et al. [31] analyzed the factors influencing the green technology innovation behavior (GTIB) and have constructed a theoretical model and an index system for enterprises' green development behaviors. Furthermore, Zhang et al. [32] proved that government policies, specifically the national innovative city pilot policy (NICP), exerted a positive influence on green development. The analysis of influencing factors in the above-mentioned literature shows that the popularization and the implementation of green construction practices have attracted the attention of researchers. Table 1 shows the contribution of previous authors. Nevertheless, as a novel building paradigm within the Chinese construction industry, studies on promoting green construction practices from the perspective of RORC remain conspicuously absent.

In the other existing studies, various research methods have been used to analyze influencing factors. For instance, the Delphi method [33], the decision-making and trial evaluation laboratory (DEMATEL) method [34], and the fuzzy comprehensive evaluation method [35] have frequently been used to identify and analyze influencing factors. Moreover, in tandem with the evolution of simulation software, structural equation models [36] and system dynamics models [37] have been favored by researchers.

A comprehensive review of the literature suggests that green construction is an inexorable trajectory in the sustainable development of the construction industry for the foreseeable future. Furthermore, it is evident that green construction technologies have undergone rapid advancement in their respective domains.

Table 1. Author contribution table.

Authors	Green Construction	Factor Analysis	Specific Focus	Mathematical Techniques
Qi et al. [25]	√	√	State-owned coal mining enterprises in China	A two-step fuzzy DEMATEL method
Qi et al. [26]	√	√	Construction contractors in China	Factor analysis method
Jiang et al. [27]	√	√	Prefabricated construction in China	Structural equation model
Wang et al. [28]	√	Barriers	Green construction technologies in China	Nonprobability sampling technique
Shi et al. [29]	√	Barriers	Major stakeholders of the construction industry in Shanghai	Questionnaire survey
Li et al. [30]	√	√	Green development behaviors of construction enterprises in China	Artificial neural network
Li et al. [31]	√	√	Green technology innovation behavior of construction enterprises in China	Vector autoregressive model
Zhang et al. [32]	√	Single factor	National innovative city pilot policy in China	PSM-DID
This paper	√	√	Renovation of old residential communities in China	Hybrid decision-making framework

However, it is noteworthy that there has been a paucity of research conducted on the underlying mechanisms of influencing factors within the context of green construction practices in RORC in China. This gap in research presents an area ripe for exploration. Therefore, this study endeavors to address this critical issue.

3. Methodology

Using rigorous scientific research methods to establish an effective analytical system is essential for comprehending the driving factors behind green construction practices in RORC. Prior studies, such as Sun et al. [38] and Giri et al. [39], have demonstrated the efficacy of the fuzzy DEMATEL method in the analysis of these driving factors. Consequently, the fuzzy DEMATEL method has been selected as the preferred approach for this study.

Nevertheless, the popularization of green construction practices in RORC is an intricate, systematic endeavor. In the Chinese context, this concept remains relatively novel, and researchers and managers may lack comprehensive background knowledge. Consequently, there is a risk of incomplete screenings and inaccurate evaluations of influencing factors, which can significantly impact the research outcomes. However, this study endeavors to augment the depth of assessment information and enhance credibility by leveraging fuzzy theory principles [40].

In this study, a novel approach is employed by combining the grounded theory, the fuzzy DEMATEL method, and analytic network process (ANP) method. The hybrid framework is proposed to comprehensively analyze the multifaceted factors influencing the implementation of green construction practices in RORC.

3.1. Advantage Analysis of the Hybrid Framework

The hybrid framework employed in the analysis of the influencing mechanisms of the implementation of green construction practices in RORC has three advantages:

1. It enhances the validity and integrity of the influencing factors. By using the grounded theory, this paper organized and analyzed the existing references and interview records, and extracted the corresponding indicators. This process ensures the scientific rigor, consistency, and objectivity of the indicator selection process.
2. It ensures a scientific and reasonable research conclusion. Using the fuzzy DEMATEL method and ANP method, the comparison of indirect advantages among factors is increased, which is consistent with the complex application conditions in which the factors interact with each other, making the conclusion closer to the reality.
3. The combined weights take into account the concurrence or reconciliation of each approach. The amalgamated weighting technique, founded on an improved game theory framework, considers the consensus or compromise between different approaches. This approach minimizes the biases and ultimately results in the most rational combination of weights.

3.2. Establishment of the Study Framework

This study aims to identify the factors influencing the utilization of green construction practices and their interconnectedness in RORC. In order to achieve this purpose, there are three steps in this study. A conceptual framework is constructed to outline the mechanism governing the implementation of green construction practices in RORC. The detailed steps are visualized in Figure 1.

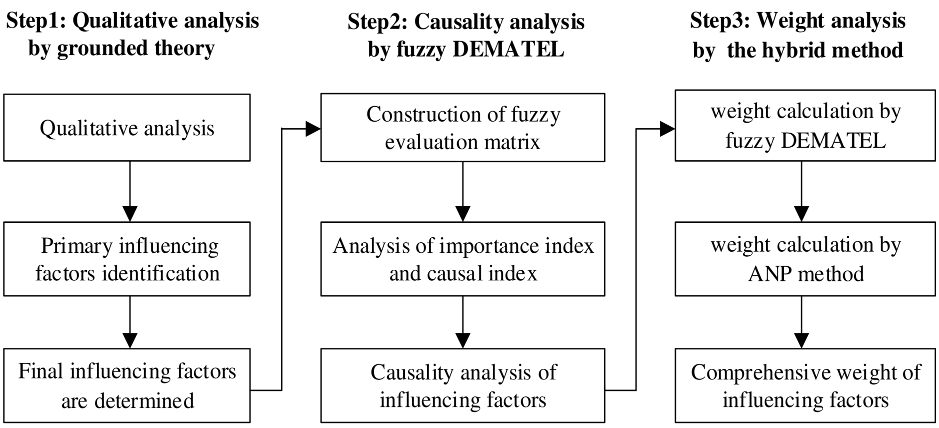

Figure 1. Framework for analyzing influential factors in implementing green construction practices in RORC.

3.2.1. Qualitative Analysis

In this paper, the ultimate goal of qualitative analysis is to scientifically determine the factors influencing the implementation of green construction practices. Grounded theory enhances quality through the method of theoretical construction [41]. Grounded theory, since its inception, has found integration across diverse domains, consistently yielding positive and insightful outcomes [42].

In this paper, grounded theory serves as the foundation for the analysis, which unfolds through a series of systematic steps, including question formulation, data collection, data coding, theory construction, and research conclusion [43]. The qualitative analysis workflow is depicted in Figure 2 for reference.

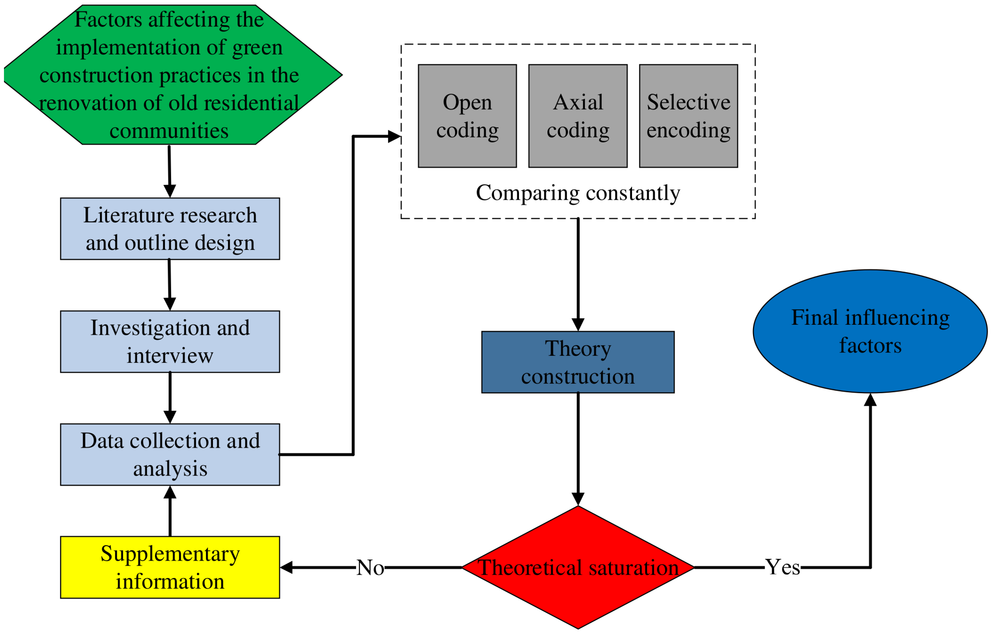

Figure 2. Qualitative analysis operating program.

In Figure 2, distinct colors denote different categories of implementation steps. It is evident that the most pivotal steps encompass open coding, axial coding, selective coding, and the testing of theoretical saturation. Specifically, open coding involves a systematic analysis and summarization of textual materials and information, performed sentence by sentence and paragraph by paragraph. This process gradually leads to the conceptualization and abstraction of intriguing concepts and categories derived from the informational datasets. Subsequently, a comparative analysis of the nodes generated during the open coding process is conducted. This assessment aims to determine the relevance between these nodes, allowing for refinement and adjustment where necessary. All nodes are systematically classified, culminating in the completion of the axial coding process. Following axial coding, an analysis and categorization of the indicators obtained from this process are performed; this is selective coding. This analysis explores the inherent relationships among these indicators. The process involves the selection of core categories, systematic linkage with other categories, validation of these connections, and identification of categories requiring further refinement and development. Finally, after the combined application of open coding, axial coding, and selective coding, the supplementary interview content is analyzed. This analysis serves to validate the accuracy and authenticity of the indicator system. When new nodes no longer emerge in the results, the construction model is considered to have achieved theoretical saturation.

3.2.2. Analysis of Fuzzy DEMATEL

In this section, the importance and causality among the factors influencing the implementation of green construction practices in RORC will be analyzed. The analysis of fuzzy DEMATEL is conducted through the following steps.

Firstly, the fuzzy initial direct-relation matrix is established by using triangular fuzzy numbers. Triangular fuzzy numbers prove to be effective in addressing situations where experts' perceptions of objective phenomena are influenced by uncertainty and fuzzy judgments [44]. The linguistic scales converted into triangular fuzzy numbers (TFNs) are illustrated in Table 1 [45]. After constructing the influencing factor system through qualitative analysis, experts who have been engaged in the old residential communities' renovation and the green construction industry for a long time rate the degree of mutual influence between the factors. Subsequently, the data are subjected to fuzzy processing, as per Table 2, to mitigate the uncertainty and subjectivity inherent in expert evaluations, resulting in the establishment of the fuzzy initial direct-relation matrix $\widetilde{A}_{ij}^{k}$.

$$\widetilde{A}_{ij}^{k} = \left[\widetilde{a}_{ij}^{k}\right]_{n\times n} = \begin{bmatrix} 0 & \widetilde{a}_{12}^{k} & \cdots & \widetilde{a}_{1n}^{k} \\ \widetilde{a}_{21}^{k} & 0 & \cdots & \widetilde{a}_{2n}^{k} \\ \vdots & \vdots & & \vdots \\ \widetilde{a}_{n1}^{k} & \widetilde{a}_{n2}^{k} & \cdots & 0 \end{bmatrix} \tag{1}$$

where $\widetilde{a}_{ij}^{k} = (l_{ij}^{k}, m_{ij}^{k}, r_{ij}^{k})$ indicates the score of expert k regarding the importance of factor i on factor j.

Table 2. The linguistic scale and corresponding TFN.

Linguistic Scale	Score	TFN
No influence	0	(0,0,0.25)
Very Low influence	1	(0,0.25,0.5)
Low influence	2	(0.25,0.5,0.75)
High influence	3	(0.5,0.75,1)
Very High influence	4	(0.75,1,1)

Then, the fuzzy data will be converted into crisp scores, involving a defuzzification process with four distinct steps [46]. This process involves standardization, which is accomplished through Equations (2)–(5). The left and right standard values are calculated using Equations (6) and (7), the exact value of the total standard is calculated using Equation (8), and the definite value and average definite value are calculated using Equations (9) and (10).

$$\Delta_{\min}^{\max} = \max r_{ij}^{k} - \min l_{ij}^{k} \tag{2}$$

$$\chi^{l_{ij}^{k}} = \frac{l_{ij}^{k} - \min l_{ij}^{k}}{\Delta_{\min}^{\max}} \tag{3}$$

$$\chi^{m_{ij}^{k}} = \frac{m_{ij}^{k} - \min l_{ij}^{k}}{\Delta_{\min}^{\max}} \tag{4}$$

$$\chi^{r_{ij}^{k}} = \frac{r_{ij}^{k} - \min l_{ij}^{k}}{\Delta_{\min}^{\max}} \tag{5}$$

$$\chi^{ls_{ij}^{k}} = \frac{\chi^{m_{ij}^{k}}}{1 + \chi^{m_{ij}^{k}} - \chi^{l_{ij}^{k}}} \tag{6}$$

$$\chi^{rs_{ij}^{k}} = \frac{\chi^{r_{ij}^{k}}}{1 + \chi^{r_{ij}^{k}} - \chi^{m_{ij}^{k}}} \tag{7}$$

$$\chi_{ij}^{k} = \frac{\chi^{ls_{ij}^{k}}(1 - ls_{ij}^{k}) + (\chi^{rs_{ij}^{k}})^{2}}{1 - \chi^{ls_{ij}^{k}} + \chi^{rs_{ij}^{k}}} \tag{8}$$

$$a_{ij}^{k} = \min l_{ij}^{k} + \chi_{ij}^{k} \times \Delta_{\min}^{\max} \tag{9}$$

$$a_{ij} = \frac{(a_{ij}^{1} + a_{ij}^{2} + \cdots + a_{ij}^{k})}{k} \tag{10}$$

Then, the direct-relation matrix A is obtained as follows:

$$A = (a_{ij})_{n\times n} = \begin{bmatrix} 0 & a_{12} & \cdots & a_{1n} \\ a_{21} & 0 & \cdots & a_{2n} \\ \vdots & \vdots & & \vdots \\ a_{n1} & a_{n2} & \cdots & 0 \end{bmatrix} \tag{11}$$

where $i, j = 1, 2, 3, \cdots, n$.

Then, the fuzzy normalized direct-relation matrix N is calculated as follows.

$$N = A/Q \tag{12}$$

$$Q = \max_{1\le i\le n} \sum_{j=1}^{n} a_{ij} \tag{13}$$

Then, the fuzzy total relation matrix T is calculated as follows.

$$T = \lim_{n\to\infty}(N + N^2 + N^3 + \cdots + N^n) = \sum_{n=1}^{\infty} N^n = N(1-N)^{-1} = [t_{ij}]_{n\times n} \tag{14}$$

Then, the degree of influence (D_i), influenced (C_j), centrality (M_i), and causation (R_i) of each factor are calculated as follows [47]:

$$D_i = \sum_{j=1}^{n} t_{ij},\ i = 1, 2, \cdots, n \tag{15}$$

$$C_j = \sum_{i=1}^{n} t_{ij},\ j = 1, 2, \cdots, n \tag{16}$$

$$M_i = D_i + C_j \tag{17}$$

$$R_i = D_i - C_j \tag{18}$$

where D_i denotes the degree of influence of one factor on another in each row, and C_j signifies this in each column. M_i denotes the position and role of this factor whthin the entire network of influencing factors. R_i indicates the extent of the causality. If $R_i > 0$, it is considered the cause factor, exerting significant influence on other factors. If $R_i < 0$, it is regarded as the result factor, which is greatly affected by other factors.

Then, M_i and R_i can be used to construct an influence relationship diagram that shows the causal relationships of the factors.

Lastly, referring to an existing study [48], the weight of influencing factors can be obtained by using the fuzzy DMEATEL method. The weight Z_j^d is shown as follows.

$$Z_j^d = \frac{M_i}{\sum_{i=1}^{n} M_i} \tag{19}$$

3.2.3. Construction of ANP Network

The network hierarchy of ANP divides the system elements into two levels [49]. The first layer is the control layer, that is, the problems that need to be solved and the decision-making criteria. The second layer is the network layer, where all the elements within this layer are under the influence of the control layer, and there is an interactive network structure among the elements of this layer. The network hierarchy of ANP is shown in Figure 3.

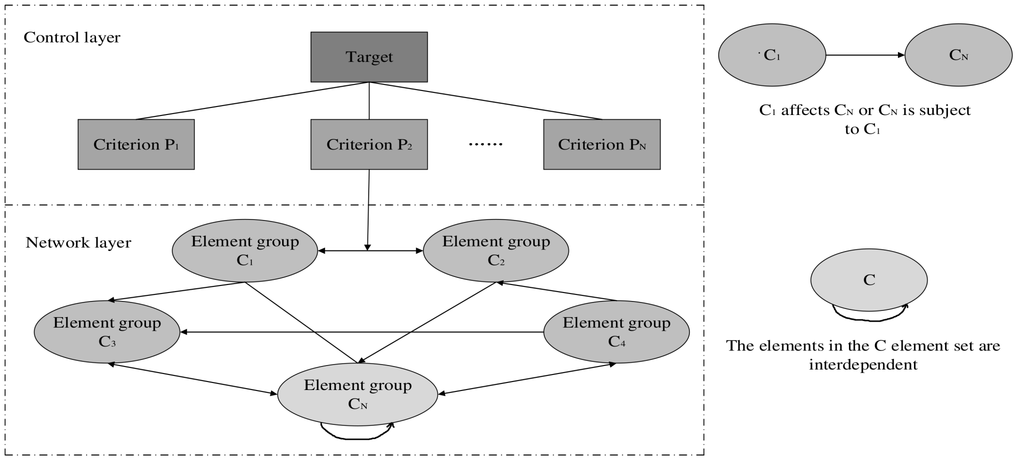

Figure 3. The network hierarchy of ANP.

The ANP network serves as a framework to judge the weight of each factor from the perspective of hierarchical relationships. For this purpose, the construction of ANP network is executed in the following steps.

Firstly, based on the results identified through qualitative analysis, an element set encompassing the first-level influencing factors is created in the super decision (SD) software. Subsequently, the second-level influencing factors are incorporated into the element set in turn.

Then, according to the correlation between the factors and the network structure diagram, the dependence and feedback relationship between the factors is established within the SD software.

Thirdly, a questionnaire is designed by combining the network structure and the initial direct-relation matrix. Then, experts are invited to compare the advantages of pairwise factors according to the scoring scale. Following this, the questionnaire data are summarized, and the importance matrix among related factors under the influence of each factor is input into the SD software.

Lastly, the SD software is employed to generate the matrix in turn. This comprises unweighted hypermatrices W, weighted hypermatrices $\overline{W}$, extreme hypermatrices $\overline{W}^{\infty}$, and global weight Z_j^a of the factors.

3.2.4. Calculation of Mixed Weight

This paper introduces a combined weighting method based on an improved game theory approach. The influence of the minimum deviation in the traditional mixed weighting method based on game theory is further considered.

Based on the ANP weight vector Z^a and the fuzzy DEMATEL weight vector Z^d mentioned above, the mixed weight Z_j can be expressed as a linear combination.

$$Z_j = \alpha Z_j^d + (1-\alpha) Z_j^a \tag{20}$$

Firstly, when using the traditional comprehensive weighting method based on game theory, it is assumed that the mixed weights can be represented through the following linear combination [50]:

$$Z_j = \theta Z^d + (1-\theta) Z^a \tag{21}$$

$$\begin{cases} \min\|\theta_1 (Z^a)^T + \theta_1 \left(Z^d\right)^T - (Z^a)^T\|_2 \\ \min\|\theta_2 (Z^a)^T + \theta_2 \left(Z^d\right)^T - (Z^a)^T\|_2 \end{cases} \tag{22}$$

where θ_1 and θ_2 are the combination coefficients of Z^a and Z^d, respectively. When θ_1 and θ_2 are normalized, the following expression can be obtained.

$$\theta = \frac{\theta_2}{\theta_1 + \theta_2}, \tag{23}$$

Then, the objective function is formulated to minimize the sum of squares of deviations between Z_j^a, Z_j^d, and Z_j, respectively.

$$min = \sum_{j=1}^{m} [(Z_j - Z_j^a)^2 + (Z_j - Z_j^d)^2], \tag{24}$$

By combining Equations (24) and (20), another combination coefficient γ can be obtained.

The combination coefficient α based on improved game theory can be obtained as follows.

$$\alpha = (\theta + \gamma)/2 \tag{25}$$

By sorting the mixed weights of the influencing factors, several factors that significantly influence the driving force of green construction practices in RORC can be identified and controlled emphatically.

4. Case Analysis

4.1. Identification of Key Drivers for Green Construction Practices in RORC

Drawing upon a comprehensive examination of scholarly literature and interview transcripts, grounded theory methodology was adopted. In this study, the China National Knowledge Infrastructure (CNKI) and Web of Science (WOS) served as databases for the retrieval of scholarly literature. Subject terms such as ”old residential”, “existing buildings”, and “residential communities” were combined individually with “influencing factors” and “green”, yielding a total of 58 papers found in the CNKI database. Subsequent to a thorough analysis of the selected literature, we excluded papers with significant discrepancies in content and those categorized as purely review papers, ultimately retaining 15 pertinent papers. Within the WOS database, an initial 112 papers were identified and, after rigorous screening, 7 papers were deemed relevant. To enrich our research sample, an additional 5 papers related to influential factors in green construction were selected, and these papers were not only highly cited within the existing literature but also highly relevant to our study. Thus, the final literature sample database comprised a total of 27 papers. Acknowledging the limitations of the literature sample scale, in-depth interviews were conducted with key stakeholders engaged in the green renovation of old residential communities to acquire deeper insights into the mechanisms of influence. A total of 15 interviews were conducted, featuring participants comprising 6 eminent scholars from academic institutions specializing in green construction and RORC, 4 government officials overseeing green development and RORC, and 5 managerial personnel from construction enterprises engaged in RORC projects. Ultimately, as it proved unfeasible to extract novel categories from the research subjects, our endeavor to derive novel categories from them reached a point of theoretical saturation. Subsequently, these resources were subjected to meticulous coding and analysis through the utilization of NVivo 12 software.

The theoretical analysis process, spanning stages encompassing coding and theoretical saturation, has yielded the factors driving the popularization and implementation of green construction practices in RORC. The findings are presented in Table 3.

Table 3. Driving factors of green construction practices in RORC.

Selective Coding	Axial Coding	Open Coding	Connotation
Market environment	Contractors' implementation intentions.	Sustainable design philosophy (M1) Market competition (M2) Degree of industry standardization (M3)	Contractor's willingness toward implementation is influenced by current industry policies, market competitiveness, and the sustainable design philosophy in the context of green development in RORC.
	Real needs of the residents.	Residents' strong desire for a healthy, energy-efficient, and comfortable living environment (M4)	The real needs of the residents are to ensure a favorable environment for them both during and after RORC.
	The level of research and development in green construction technology.	Innovation of green construction modality (M5) Green construction technology process (M6) Research and development of green construction materials (M7)	The level of research and development in green construction technology, encompassing the innovation of green construction modality, the green construction technology process, and green construction materials, can furnish technical underpinning for the sustainable development of RORC.
	Green construction management mode.	Project management system including efficiency optimization and resource integration(M8) Environmental and social responsibility in the construction process (M9)	Green construction management mode exerts a positive influence on the green construction of RORC projects by enhancing efficiency, minimizing waste, mitigating environmental impacts, and fostering social responsibility. These effects play a pivotal role in promoting the adoption of green construction practices.
Economic benefits	Cost of green construction.	Green construction costs (E1)	Additional costs associated with the implementation of green construction practices in RORC.

Table 3. *Cont.*

Selective Coding	Axial Coding	Open Coding	Connotation
Economic benefits	Incremental investment in the green construction market.	Incremental investment (E2)	The main way for enterprises to carry out market expansion is incremental investment.
	Payback period of green construction.	Investment payback period (E3)	The enthusiasm of the implementers for investing in green construction is affected by the length of the payback period.
Ecological sustainability	Quality of residents' living environment.	Healthy living Space (S1) Disruption to residents' livelihoods caused by construction (S2) Energy efficiency and environmental conservation (S3)	Residents ' healthy living spaces, efficient energy utilization, and a favorable construction environment contribute to the enhancement of the quality of residents' living environment.
	Economical utilization of resources.	Water and land saving technology (S4)	Resource saving and utilization is influenced by water saving and land saving.
	Pollution control.	Waste reduction (S5)	Reducing waste emissions is conducive to pollution control.
	Utilization of sustainable construction materials.	Utilization of green construction materials (S6)	Reasonable selection of green construction materials facilitates the achievement of the green construction goal of "four conservation and one environmental protection".
Social participation	Social satisfaction.	Government recognition and commendation (G1) Residents' feedback on the renovation process and outcomes (G2)	Social satisfaction primarily encompasses the satisfaction of stakeholders such as the government and residents.
	Government support efforts.	Financial support (G3) Policies and regulations (G4) Education and training of talents (G5) Environmental supervision (G6) Government's macro-control (G7)	The government's financial support and incentive policies can encourage enterprises to adopt and develop green construction technology, while the government 's macro-control and environmental supervision can compel the market and enterprises to develop green construction technology. Additionally, promoting the training of professionals in the field of green construction in society can provide assurance for the practical implementation of green construction.

Table 3. *Cont.*

Selective Coding	Axial Coding	Open Coding	Connotation
Social participation	Green construction reputation.	Media and public opinion guidance (G8) Social media and word-of-mouth marketing (G9) Supply chain support (G10)	Guidance from media and public opinion, promotion from media, and support from the supply chain all contribute to the implementation of green construction practices.
Technological sustainability	Adaptability of technology.	Green construction technology perception (T1)	The adaptability of technology is affected by the perception of green construction technology, which mainly includes the feasibility and applicability of green construction technology.
	Security of technology.	Safety in the use of green construction technology (T2)	Only by ensuring the safety of technology applications can it be recognized by residents, thereby promoting the sustainable development of green construction technology.
	Innovation of technology.	Level of enterprise intelligence and digitization (T3)	The level of enterprise intelligence and digitization directly affects the innovation of green construction technology.

4.2. Analysis of Influencing Factors Using Fuzzy DEMATEL Method

4.2.1. In-Depth Analysis of Factors Influencing Green Construction Practices

Given that RORC has recently emerged as a relatively novel construction paradigm in China, and green development stands as a primary developmental objective in the nation, the precise execution of these projects remains in an exploratory phase. Both construction methodologies and project components are continuously undergoing refinement and evolution. Consequently, the comprehension of this subject matter by conventional scholars and practitioners may not delve deeply enough. Hence, during the process of expert selection, it becomes imperative to identify individuals who possess a profound understanding of green construction within the context of RORC. For this study, three experts deeply engaged in both research and practical activities related to RORC were enlisted. These experts represent diverse domains, encompassing academia, government, and corporate enterprises. Among them, the academic expert has been actively involved in green development research for an extended period. In recent years, he has also made substantial contributions to the field of RORC, serving as a consultant to government agencies tasked with implementing such projects. The government expert, conversely, brings extensive experience in overseeing prior urban renewal initiatives and currently holds the responsibility for supervising RORC and energy retrofitting of existing buildings in the local region. The corporate sector expert occupies a senior management role in a large publicly listed construction enterprise and has actively participated in numerous projects involving RORC in recent years, amassing invaluable expertise. Therefore, the insights offered by these three experts on green construction within the context of RORC are instrumental in ensuring the efficacy of the research findings.

These experts employed a triangular fuzzy language to assess the relative significance of each factor and established a fuzzy evaluation matrix. The process of working with these experts was facilitated, and all three experts were equally weighted and played equally important roles. Within Table 4, the standardization of the fuzzy matrix was accomplished through Equations (2)–(5), while the standardization process of fuzzification was executed using Equations (6)–(10). The initial direct-relation matrix was computed following Equation (11). Subsequently, the fuzzy total relation matrix, as presented in Table 5, was determined through Equations (12)–(14). The relevant indicators were then derived and elucidated in Table 6.

Table 4. Initial direct-relation matrix (partial).

Z	M1	M2	M3	M4	M5	M6	M7	M8	M9	E1	E2	E3
M1	0	0.5000	0.7500	0.9166	0.7500	0.5000	0.5000	0.0833	0.5000	0.7500	0.5000	0.5000
M2	0.7500	0	0.9166	0.7500	0.9166	0.7500	0.7500	0.9166	0.7500	0.9166	0.7500	0.7500
M3	0.7500	0.5000	0	0.7500	0.2500	0.5000	0.0833	0.2500	0.5000	0.2500	0.5000	0.5000
M4	0.5000	0.7500	0.5000	0	0.5000	0.7500	0.7500	0.5000	0.5000	0.5000	0.7500	0.7500
M5	0.5000	0.5000	0.5000	0.5000	0	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
M6	0.5000	0.5000	0.5000	0.5000	0.5000	0	0.5000	0.5000	0.5000	0.5000	0.0833	0.5000
M7	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0	0.5000	0.5000	0.5000	0.5000	0.5000
M8	0.7500	0.9166	0.7500	0.5000	0.9166	0.9166	0.9166	0	0.7500	0.9166	0.9166	0.9166
M9	0.9166	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500	0	0.0833	0.7500	0.7500
E1	0.7500	0.5000	0.5000	0.7500	0.5000	0.5000	0.5000	0.5000	0.7500	0	0.5000	0.5000
E2	0.7500	0.7500	0.5000	0.7500	0.5000	0.7500	0.7500	0.5000	0.7500	0.5000	0	0.7500
E3	0.9166	0.5000	0.7500	0.5000	0.7500	0.5000	0.5000	0.7500	0.5000	0.7500	0.5000	0

Table 5. The fuzzy total relation matrix (partial).

T	M1	M2	M3	M4	M5	M6	M7	M8	M9	E1	E2	E3
M1	0.077	0.093	0.109	0.111	0.11	0.093	0.094	0.08	0.093	0.107	0.093	0.093
M2	0.122	0.088	0.131	0.12	0.133	0.118	0.119	0.127	0.117	0.13	0.118	0.118
M3	0.108	0.095	0.082	0.107	0.093	0.095	0.081	0.088	0.095	0.091	0.096	0.096
M4	0.09	0.097	0.093	0.07	0.094	0.097	0.098	0.09	0.087	0.092	0.097	0.097
M5	0.079	0.076	0.081	0.078	0.063	0.076	0.077	0.078	0.076	0.08	0.076	0.076
M6	0.078	0.075	0.08	0.077	0.081	0.056	0.076	0.077	0.075	0.079	0.06	0.075
M7	0.08	0.078	0.082	0.079	0.083	0.078	0.059	0.08	0.077	0.081	0.078	0.078
M8	0.12	0.122	0.123	0.109	0.132	0.122	0.123	0.091	0.115	0.129	0.122	0.122
M9	0.122	0.111	0.119	0.114	0.12	0.112	0.113	0.115	0.082	0.092	0.112	0.112
E1	0.115	0.101	0.108	0.113	0.109	0.101	0.102	0.104	0.11	0.087	0.101	0.102
E2	0.109	0.105	0.103	0.108	0.104	0.105	0.107	0.099	0.105	0.101	0.077	0.106
E3	0.101	0.081	0.097	0.083	0.097	0.082	0.082	0.093	0.081	0.095	0.082	0.062

Table 6. Indicators of importance and cause analysis.

	D_i	C_j	M_i	R_i
M1	2.995	3.168	6.163	−0.173
M2	3.621	3.001	6.622	0.62
M3	3.045	3.269	6.314	−0.223
M4	2.754	3.103	5.857	−0.349
M5	2.315	3.316	5.63	−1.001
M6	2.272	3.009	5.281	−0.737
M7	2.355	3.054	5.409	−0.7
M8	3.55	3.118	6.668	0.433
M9	3.368	2.991	6.358	0.377
E1	3.296	3.212	6.508	0.084
E2	3.113	3.019	6.133	0.094

Table 6. *Cont.*

	D_i	C_j	M_i	R_i
E3	2.545	3.02	5.566	−0.475
S1	2.731	3.206	5.937	−0.475
S2	2.193	2.981	5.175	−0.788
S3	3.071	3.208	6.279	−0.137
S4	2.365	3.206	5.571	−0.841
S5	3.205	3.067	6.272	0.138
S6	0.995	3.08	4.075	−2.084
G1	3.519	2.396	5.915	1.124
G2	2.79	2.906	5.696	−0.117
G3	3.205	2.669	5.874	0.536
G4	3.093	2.992	6.085	0.101
G5	2.882	3.21	6.092	−0.328
G6	3.086	2.535	5.62	0.551
G7	3.34	2.831	6.171	0.509
G8	3.877	3.197	7.074	0.68
G9	3.911	2.435	6.346	1.476
G10	3.445	2.702	6.147	0.743
T1	3.445	2.659	6.105	0.786
T2	3.173	3.232	6.405	−0.059
T3	2.753	2.517	5.271	0.236

In Table 6, D_i, C_j, M_i, and R_i were calculated using Equations (15)–(18), respectively. The degree of centrality (M_i) reflects the importance of a factor influencing green construction in RORC. Moreover, the degree of causality (R_i) is the net influence of a factor on promoting green construction practices in RORC after excluding acceptable influences.

4.2.2. Causality Analysis

In this section, a causal diagram depicting the relationships between the driving factors of green construction practices in the context of RORC is constructed. The horizontal axis represents data M_i, while the vertical axis represents data R_i, as illustrated in Figure 4.

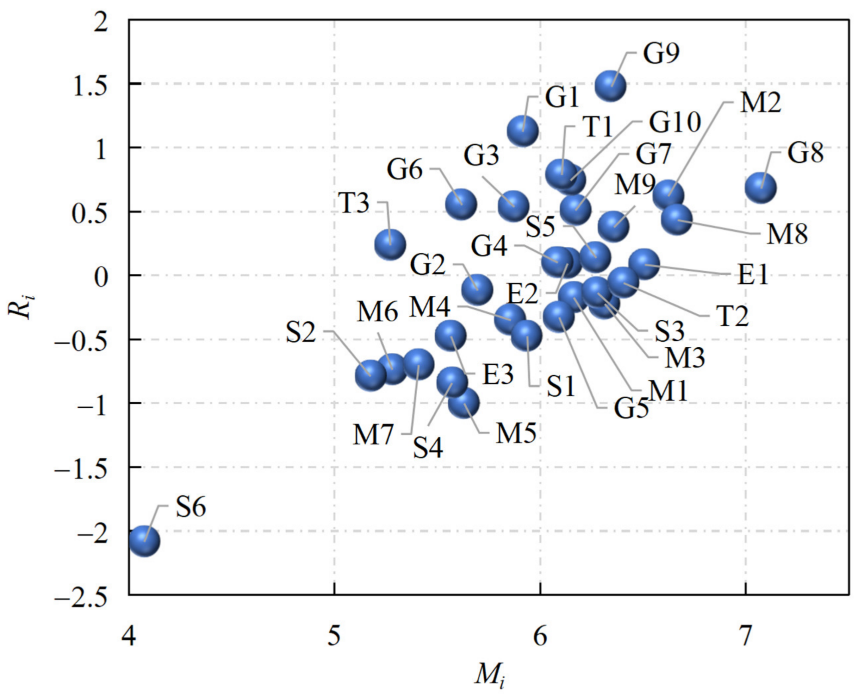

Figure 4. Causal relationship diagram of influencing factors.

In terms of the degree of influence, the factors with the highest impact on the popularization and implementation of green construction practices in RORC are social media and word-of-mouth marketing (G9), media and public opinion guidance (G8), market competition (M2), government recognition and commendation (G1), supply chain support (G10), and green construction technology perception (T1). Their influence degrees are measured at 3.911, 3.877, 3.621, 3.519, 3.445, and 3.445, respectively. These six factors rank as the most significant among the 31 influencing factors, indicating that they exert the greatest influence on other factors.

Centrality, on the other hand, reflects the importance of various influencing factors in driving green construction practices in RORC. From a centrality perspective, media and public opinion guidance (G8), project management system (M8), market competition (M2), green construction costs (E1), security in the use of technology (T2), environmental and social responsibility (M9), and social media and word-of-mouth marketing (G9) exhibit relatively high centrality values. This suggests that these factors hold the greatest influence on driving green construction practices. Among them, the value of G8 stands out as the highest, emphasizing that effective media and public opinion guidance plays a pivotal role in the successful adoption of green construction practices in RORC. Conversely, the value of S6 is relatively low, indicating its lesser importance in driving green construction practices in RORC.

The causal degree values can be either positive or negative, representing opposing directions of action. In terms of influencing factors from high to low causal degree, the order is as follows: social media and word-of-mouth marketing (G9), government recognition and commendation (G1), green construction technology perception (T1), supply chain support (G10), media and public opinion guidance (G8), market competition (M2), environmental supervision (G6), financial support (G3), government's macro-control (G7), project management system (M8), environmental and social responsibility in the construction process (M9), innovation of green construction technology (T3), waste reduction (S5), policies and regulations (G4), incremental investment (E2), and green construction costs (E1). These factors are considered active contributors to advancing green construction practices in RORC and should be prioritized and strengthened through positive measures.

4.3. ANP Method to Determine the Weight of Influencing Factors

4.3.1. Comparison of Indirect Advantages between Related Factors

The questionnaire was designed to compare the indirect advantages among correlated factors. It aimed to evaluate the relative significance of these factors and establish an importance matrix by soliciting opinions on the relative importance of interconnected factors within a specific category.

4.3.2. Calculation of Weights

The data were organized, and the importance matrix for each factor was input into the SD matrix. The random consistency ratio (CR) was determined to be 0.08062, which is less than 0.1, indicating a satisfactory level of consistency. Then, SD software was used to calculate W, $\overline{W}$, $\overline{W}^{\infty}$, and Z_j^a based on Equations (21)–(23). Consequently, the value of θ was determined to be 0.4, and based on Equation (25), α was found to be 0.45. Subsequently, the mixed weights for each influencing factor were computed, and the normalized weights for each secondary influencing factor were derived through further processing of the mixed weights, as presented in Table 7.

Table 7. Weight of each influencing factor.

First Grade Indicators	Weight	Secondary Indicators	Z_j^a	Z_j^d	Z_j
M	0.3129	M1	0.0409	0.0330	0.0370
		M2	0.0643	0.0360	0.0520
		M3	0.0447	0.0340	0.0399
		M4	0.0141	0.0320	0.0224
		M5	0.0124	0.0300	0.0203
		M6	0.0086	0.0290	0.0178
		M7	0.0097	0.0290	0.0184
		M8	0.0875	0.0360	0.0643
		M9	0.0464	0.0340	0.0408
E	0.1023	E1	0.0579	0.0350	0.0476
		E2	0.0377	0.0330	0.0356
		E3	0.0102	0.0300	0.0191
S	0.1518	S1	0.0200	0.0320	0.0254
		S2	0.0069	0.0280	0.0164
		S3	0.0445	0.0340	0.0398
		S4	0.0109	0.0300	0.0195
		S5	0.0439	0.0340	0.0394
		S6	0.0026	0.0220	0.0113
G	0.3374	G1	0.0184	0.0320	0.0245
		G2	0.0128	0.0310	0.0209
		G3	0.0152	0.0320	0.0228
		G4	0.0250	0.0330	0.0286
		G5	0.0320	0.0330	0.0325
		G6	0.0115	0.0300	0.0198
		G7	0.0415	0.0330	0.0377
		G8	0.1032	0.0380	0.0739
		G9	0.0453	0.0340	0.0402
		G10	0.0393	0.0330	0.0365
T	0.0945	T1	0.0336	0.0330	0.0333
		T2	0.0516	0.0350	0.0441
		T3	0.0074	0.0290	0.0171

4.4. Results and Discussion

4.4.1. Analysis of Results

An in-depth examination of the significance and weight of influential factors related to green construction practices in RORC was undertaken. Through meticulous analysis, this study illuminates the key factors that propel the popularization and implementation of green construction practices in RORC.

Firstly, in the exploration of the driving factors for green construction practices in RORC, the weights of the primary first-grade influencing factors, social participation and the market environment, are 0.3374 and 0.3129, respectively. These weights are approximately equal and the highest, signifying the critical role of these two factors in driving green construction practices in RORC. The centrality and causality analyses also demonstrate that the secondary factors with significant influence and importance mostly fall under these two primary aspects. Hence, enhancing the involvement of various stakeholders and clearly understanding the market environment are essential for promoting green construction practices in RORC.

Subsequently, when considering the secondary influencing factors, which take into account mutual relationships and relative importance weights, the mixed weights are calculated. The results reveal that factors such as media and public opinion guidance (G8) with a weight of 0.0739, project management system (M8) with a weight of 0.0643, market competition (M2) with a weight of 0.0520, green construction costs (E1) with a weight of 0.0476, safety in the use (T2) with a weight of 0.0441, environmental and social responsibility in the construction process (M9) with a weight of 0.0408, social media and word-of-mouth marketing (G9) with a weight of 0.0402, and several others, all have weights exceeding 0.04, indicating their significant importance and warranting closer attention. Notably, degree of industry standardization (M3) with a weight of 0.0399, energy efficiency and environmental conservation (S3) with a weight of 0.0398, waste reduction (S5) with a weight of 0.0394, government's macro-control (G7) with a weight of 0.0377, sustainable design philosophy (M1) with a weight of 0.0370, supply chain support (G10) with a weight of 0.0365, incremental investment (E2) with a weight of 0.0356, green construction technology perception (T1) with a weight of 0.0333, and education and training of talents (G5) with a weight of 0.0325, are closely aligned in importance and should be developed in tandem. In addition, factors like policies and regulations (G4) with a weight of 0.0286, healthy living space (S1) with a weight of 0.0254, government recognition and commendation (G1) with a weight of 0.0245, financial support (G3) with a weight of 0.0228, residents' strong desire for a favorable living environment (M4) with a weight of 0.0224, residents' feedback (G2) with a weight of 0.0209, innovation of green construction modality (M5) with a weight of 0.0203, environmental supervision (G6) with a weight of 0.0198, wate and land saving technology (S4) with a weight of 0.0195, investment payback period (E3) with a weight of 0.0191, research and development of green construction materials (M7) with a weight of 0.0184, green construction technology process (M6) with a weight of 0.0178, green construction technology innovation (T3) with a weight of 0.0171, disruption to residents' livelihoods caused by construction (S2) with a weight of 0.0164, and utilization of green construction materials (S6) with a weight of 0.0113, hold relatively smaller weights.

In summary, the factors influencing green construction practices in RORC are primarily driven by the media and public opinion guidance, project management system, and market competition. To effectively apply green construction practices in RORC, it is crucial to first establish a strong green building reputation, followed by the implementation of a mature green construction management model and a thorough understanding of the market competition environment for green construction practices to promote its development.

4.4.2. Discussion of Results' Sensitivity

The purpose of sensitivity analysis is to identify the impact of an expert's decision weight on the ultimate result, assess the authenticity and dependability of the data, and grasp the influence of varying weight combinations assigned by diverse decision assessors on the result.

Initially, an equal weight distribution is allocated to each expert, followed by the adjustment of weights based on individual experts' experience, job positions, and years of professional service, allowing for an analysis of result variations. Notably, the second expert and the three highly experienced experts are subjected to similar weight adjustments in the sensitivity analysis. Table 8 shows the hypotheses resulting from varying combinations of expert weights.

Table 8. The hypotheses of different weight combinations.

	Hypothesis One	**Hypothesis Two**	**Hypothesis Three**	**Hypothesis Four**	**Hypothesis Five**
Expert 1	0.33	0.1	0.2	0.4	0.5
Expert 2	0.33	0.45	0.40	0.3	0.25
Expert 3	0.33	0.45	0.40	0.3	0.25

Through a comparative analysis of Figure 5 and Table 9, it becomes evident that the factors considered in the five cases exhibit a high degree of consistency, affirming their reliability and validity. In essence, the results in this study are consistent with the sensitivity analysis process. However, Figure 5 indicates that the importance index and the causal index, under distinct weight configurations, do not perfectly coincide. This suggests that different expert weights exert an influence. From the perspective of the importance index, this influencing factor demonstrates a relatively strong connection with other influencing factors. While the amplitude of fluctuation varies across different expert weight combinations, the overall trend remains consistent. Thus, it is believed that each expert holds varying perspectives regarding the degree of interconnection between these indicators. Consequently, the importance index values obtained under diverse expert weightings differ, but the underlying relationships between the indicators remain consistent. Therefore, the findings meet with the requirements of the study.

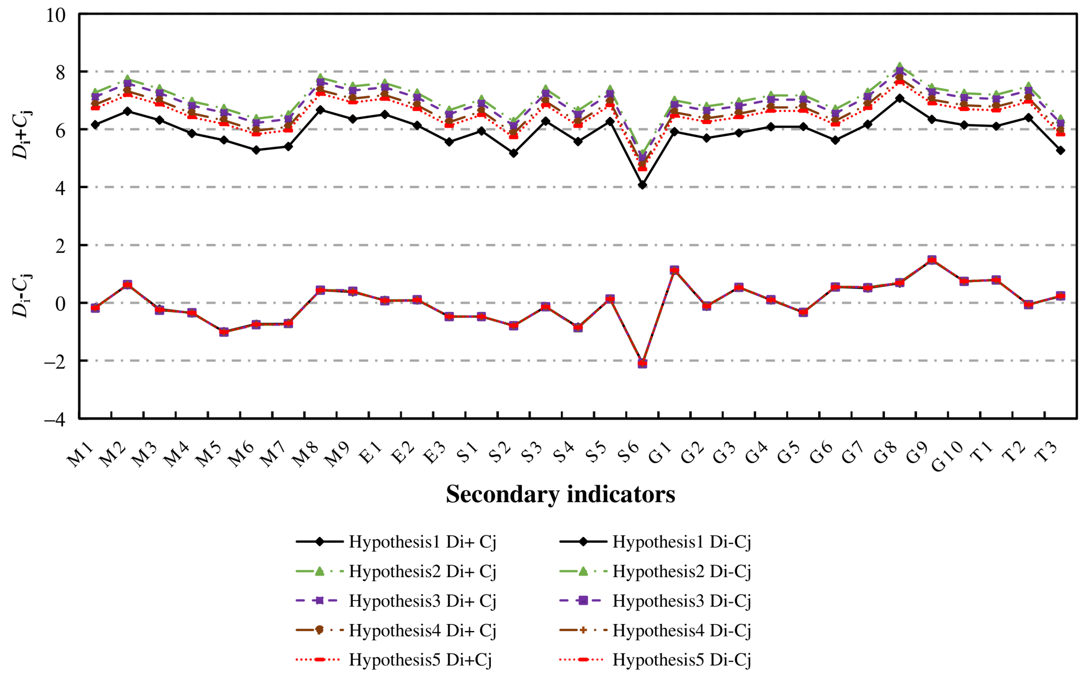

Figure 5. Sensitivity analysis of different experts' weight.

Table 9. Results of sensitivity analysis (partial).

	Hypothesis One		Hypothesis Two		Hypothesis Three		Hypothesis Four		Hypothesis Five	
	$D_i + C_j$	$D_i - C_j$	$D_i + C_j$	$D_i - C_j$	$D_i + C_j$	$D_i - C_j$	$D_i + C_j$	$D_i - C_j$	$D_i + C_j$	$D_i - C_j$
E1	6.508	0.084	7.596	0.073	7.452	0.074	7.183	0.077	7.058	0.078
E2	6.133	0.094	7.251	0.114	7.103	0.111	6.827	0.106	6.698	0.104
E3	5.566	−0.475	6.664	−0.475	6.519	−0.475	6.247	−0.475	6.121	−0.475
S1	5.937	−0.475	7.041	−0.473	6.894	−0.473	6.622	−0.474	6.495	−0.474
S2	5.175	−0.788	6.267	−0.791	6.122	−0.791	5.853	−0.79	5.727	−0.789

4.5. Further Discussion and Comparison

As an essential pillar for sustainable development, the integration of green construction practices into RORC has garnered increasing attention. Through the case study, these findings can be further promoted in the future. This paper offers several contributions to practical application based on the above-mentioned analysis results. The detailed discussions are outlined as follows:

Firstly, within some studies relating to the utilization of fuzzy DEMATEL and ANP methods, such as the work of Yang and Zhu [51], who analyzed the priority selection, and Hatefi and Tamosaitiene [52], who investigated risk factors, data collection predominantly involves elements of literature review, questionnaire survey, and expert interview. Combination weights are primarily determined by relying on ANP. In other scholarly works, experts delineate alternatives and sets of criteria for evaluation, as seen in the studies conducted by Kabak [53], Khodadadi and Aghabeigi [54], and Nasri et al. [55]. In these instances, combination weights are derived through ANP or TOPSIS. In contrast, this paper introduces grounded theory, incorporating a novel combined weighting method based on improved game theory. Grounded theory places heightened emphasis on the conceptual intensity and has the capacity to unearth rich data content as a foundation for argumentation. Thus, grounded theory offers a more comprehensive range of influencing factors when selecting the implementation of green construction practices in RORC, rendering it a scientifically rigorous acquisition method. Moreover, the combined weighting method based on improved game theory addresses the arbitrariness inherent in manually determining preference coefficients for weightings in various methods. It minimizes bias, culminating in the most rationalized combination of weights. Consequently, this research delves deeply into the implementation of green construction practices in RORC.

Subsequently, in studies addressing RORC and green development, there is a recurring theme centered on enhancing the residential community environment. For example, Dai et al. [56] scrutinized landscape preference evaluations of aging residential neighborhoods, Wei et al. [57] investigated the renovation of informal green spaces in antiquated urban residential communities, and Li et al. [58] explored strategies for ameliorating green open spaces in aging downtown residential communities. In parallel studies, attention was directed toward analyzing the impact of carbon emissions [59], the adoption of green renovation technology [60], and energy consumption [61]. Furthermore, risk management was also a focal point of investigation [62]. In this paper, an analysis of factors propelling green construction practices in RORC is conducted, constituting an in-depth extension of the research outcomes previously mentioned.

Therefore, this study, which hinges upon advancing green construction practices in RORC through a hybrid decision-making framework, serves as a theoretical basis for further research and practical implementation. The theoretical framework delineated in this paper also offers a valuable reference for the analysis of analogous challenges.

5. Conclusions and Policy Implications

5.1. Conclusions

In this study, we analyzed the factors influencing the popularization and implementation of green construction practices in RORC through the proposition of a hybrid decision-making framework. Based on the analysis and discussions presented above, this study culminates in the following conclusions:

Firstly, the hybrid framework introduced in this paper provides a robust means to assess the factors influencing green construction practices in RORC. Based on the grounded theory, 31 factors germane to green construction practices in RORC are identified. Furthermore, the fuzzy DEMATEL method and ANP method prove invaluable in determining the strength relationship, influence mechanism, and weights attributed to each of these factors.

Secondly, among these factors, it is evident that social participation and market environment emerge as the most critical factors influencing the implementation of green construction practices of RORC. Social participation encompasses the extent of engagement in the project's planning, decision-making, and implementation phases. This active involvement ensures the integration of stakeholder aspirations into the project, thereby amplifying its sustainability and prospects for success. Simultaneously, the market environment, an amalgamation of economic, policy, technology, supply, and demand considerations, fundamentally dictates the economic and market allure of a given project. Consequently, these two factors wield direct influence over the popularization and implementation of green practices in RORC.

Lastly, the nexus of favorable reputation, a well-honed management model and a conducive social environment in the realm of green construction markedly propel the popularization and implementation of green construction practices in RORC. Considering the mutual influence and relative significance of these factors, these three factors are relatively important: media and public opinion guidance (G8), project management system (M8), and market competition (M2). Therefore, in the endeavor to popularize green construction practices, we should pay attention to these three factors.

5.2. Policy Implications

Based on the above-mentioned conclusions, we can draw the following effective policy implications:

Firstly, key stakeholders should be encouraged to participate in the implementation of green construction practices in RORC. Robust mechanisms for social participation should be earnestly introduced into RORC. On one hand, from the residents' perspective, actively seeking their opinions can enhance their comprehension and endorsement of green construction practices. On the other hand, from the government's vantage point, enterprises can reap the benefits of green construction through the implementation of preferential policies.

Secondly, there is a pressing need for the broader society to cultivate a favorable market environment conducive to green construction. Through the enforcement of a suite of policies and standards, the government can stimulate the advancement of green construction technology, the assimilation of green design principles, and the integration of green construction concepts into specific construction endeavors. Such measures will serve to augment market demand and bolster confidence in green construction technology.

Lastly, it is incumbent upon us to enhance word-of-mouth publicity and supervision pertaining to green construction practices. Attention should be paid to the direction of public opinion concerning green construction. Actively disseminating success stories of green construction endeavors in RORC and showcasing their merits and accomplishments in energy conservation, environmental preservation, health enhancement, and other domains, will be instrumental. Additionally, beyond government supervision, the engagement of communities and volunteers is encouraged to assist residents in overseeing green construction initiatives.

6. Limitations

These limitations will be discussed in terms of the research methods and content. While the paper introduces a hybrid framework that combines grounded theory, the fuzzy DEMATEL method, and ANP method, it is noteworthy that the existing research on the popularization and implementation of green construction and RORC may be insufficient. Furthermore, the judgments rendered by experts regarding the factors influencing the implementation of green construction practices within the RORC may bear a degree of subjectivity. Additionally, it should be acknowledged that experts hailing from diverse professional backgrounds and academic disciplines may harbor divergent perspectives concerning the factors underpinning the implementation of green construction in RORC. Although this study has made some contributions to the research perspective, more in-depth theoretical inquiry and more precise investigation and analysis are needed in future studies. For instance, future research could be further stratified based on professional backgrounds, with a focus on discerning the varying weight of different experts on different facets of the subject matter. Another limitation to consider is this research's specific focus on the popularization and implementation of green construction practices within RORC in China. This inherently constrains the generalizability of the research findings, as some conclusions may not be universally applicable to the advancement of green construction in other countries or domains. Nonetheless, as green construction technologies continue to progress, novel influencing factors are poised to emerge, affording opportunities to supplement the research findings presented in this paper.

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