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Prefabrication Implementation Potential Evaluation in Rural Housing Based on Entropy Weighted TOPSIS Model: A Case Study of Counties in Chongqing, China

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Abstract: Prefabrication as a sustainable construction method has become a trend for use in house construction. However, the construction of rural houses in China still mainly adopts on-site construction, which also raises wasteful resources and environmental problems. Previous studies lack an evaluation system for the implementation potential of prefabricated rural housing in counties, and thus cannot provide references for the government to formulate implementation strategies. This study uses PEST analysis to establish an evaluation index system for the implementation potential of prefabricated rural housing and then evaluates 32 counties in Chongqing with urbanization rates below 90% based on the entropy weighted TOPSIS model. The results show that the weight values of the four evaluation subsystems of political, economic, social, and technological are 0.4516, 0.3152, 0.0684, and 0.1648, respectively; the nearness degrees of Dianjiang, Yubei, Jiangjin, and Rongchang are 0.5475, 0.4439, 0.4312, and 0.4103, respectively, ranking in the top four in Chongqing. The results indicate that the potential of implementing prefabricated rural housing in Chongqing is closely related to policy orientation and construction industrialization; Dianjiang, Yubei, Jiangjin, and Rongchang have the relative advantage of implementing prefabricated rural housing. Finally, this paper proposes political, economic, social, and technological suggestions for the implementation of prefabricated rural housing in Chongqing.

Keywords: prefabricated rural housing; PEST; entropy weighted TOPSIS; implementation potential; Chongqing

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1. Introduction

1.1. Research Background

Sustainability is a core issue currently in focus in the construction industry. The 2022 Global Status Report for Buildings and Construction (Buildings-GSR) shows that in 2021, the building and construction sector accounted for around 37% of energy- and process-related CO_2 emissions and over 34% of energy demand globally; the building sector's operational energy-related CO_2 emissions reached an all-time high of around 10 $GtCO_2$ [1]. This is because on-site construction has been a common construction method in the building industry for the past decades [2,3]. In addition to serious environmental damage, traditional construction methods can lead to economic and social problems, such as long construction cycles, low labor productivity, and frequent safety accidents [4]. Traditional on-site construction lacks sustainability [5]. To solve the above problems, prefabricated construction (PC) has been introduced into the construction industry [6]. Prefabricated buildings are those based on industrial production methods, where all or some parts of the building structure and the building interior are built in an integrated manner using assembly [7]. Compared with traditional on-site construction, prefabricated technology can reduce 50% of construction waste [8], save 35.82% of resources, reduce 6.61% of health damage, and reduce 3.47% of ecosystem damage [9]. Prefabricated buildings can achieve 15.6%

actual carbon reduction and 3.2% operational carbon reduction [10], effectively reducing the carbon emissions and environmental impact of the construction industry [11,12].

Against emission peak and carbon neutrality, low-carbon construction to achieve sustainability has become the focus of most countries throughout the world. In 2020, Chinese President Xi Jinping announced at the 75th UN General Assembly that China aims to peak CO_2 emissions by 2030 and work toward achieving its carbon neutrality goal by 2060 [13]. However, relevant studies show that China's construction sector is likely to reach peak carbon by 2035, five years later than the national plan [10]. Therefore, China's construction industry urgently needs to choose green and low-carbon construction methods to achieve sustainable development of the construction industry as well as contribute to slowing down climate deterioration and saving natural resources [14]. Currently, the promotion of PC has become the focus of China's construction industry [15]. However, in China, it is still concentrated in urban areas, with rural areas are obviously lagging behind [16]. Under the national strategy of China's new rural construction and rural revitalization, the material living standard of China's countryside is increasing, and a large number of rural houses are being built in a short period of time [17,18]. However, over 70% of China's rural buildings are traditional brick-and-mortar and brick-and-timber structures. Meanwhile, the remaining 30% are mainly cast-in-place reinforced concrete structures [19], which means the current building quality and environmental performance of China's countryside is not meeting the requirements of contemporary sustainable development [20]. In addition, over 90% of new rural houses in China are built by villagers on their own initiative [21], with village builders invited to build them, lacking unified planning and professional technological guidance [22], and suffering from unregulated construction [23]. The construction mode of villagers' self-built houses leads to environmental pollution [24], poor structural safety [20], poor insulation, and high energy consumption [25], which restricts the sustainable development of China's countryside [26].

The Chinese government is also aware of the urgency of solving rural construction problems, and building green and livable rural housing has become an important task [27]. Prefabrication does not only realize the unified planning of rural residential design and address the need for safety and comfort in rural housing but also realizes energy savings and emission reduction throughout the life cycle of the housing. In May 2022, the Chinese government introduced the Action Plan on Rural Construction [28], noting the implementation of the project is to improve the quality and safety of rural housing. This plan explicitly requires promoting prefabricated steel, wood, and bamboo structures. However, in rural areas, due to the high cost of prefabricated buildings and the low awareness of farmers, prefabrication implementation still needs to be improved by using government projects. China's 14th Five-Year Plan is based on the goal of carbon peaking and carbon neutrality. Rural construction is a significant area of carbon emissions in the countryside, so it has become consensus to vigorously promote the construction of prefabrication housing there. As a result, there is an urgent need to establish a scientific and practical regional evaluation system to provide a reference for implementing strategies to promote prefabricated rural housing in the region.

1.2. Methodology and Purpose

The regional evaluation system of the construction industry has been studied by scholars. Liu et al. [29] established the evaluation system of regional prefabricated development level from five dimensions–technology, economy, sustainability, enterprise development, and development environment–and then used the AHP method to determine the weights of each indicator and evaluated Jiangsu province as an example; Dou et al. [30] explored the data collection method and quantification of evaluation indicators by using the advantage of new media data collection. Wang et al. [31] extracted 33 different indicators affecting industrialized buildings from existing literature and evaluated the development level of regional industrialized buildings based on the cloud model, taking Guangzhou as an example; Jin et al. [32] determined indicators from four levels–economic, social, technological innovation, and environmental resources–and used the AHP method to determine the weight values of each indicator establishing a gray comprehensive evaluation model to assess the sustainable development level of construction industrialization in the Beijing-Tianjin-Hebei region. From this, it can be seen that the existing relevant studies on the establishment of construction industrialization index systems and evaluation methods have been more mature, and multi-criteria decision-making methods (MCDMs) are more often used for evaluation.

Multi-criteria decision-making methods (MCDM) are an important part of modern decision science and are designed to support decision-makers who are faced with multiple decision criteria and multiple decision options [33]. Currently, MCDM methods have been applied by many decision-makers and researchers to solve complex problems; for example, AHP, ELECTRE, PROMETHEE, VIKOR, TOPSIS, etc. have been proposed and extended successively [34]. One of the most widely used multi-criteria decision-making methods is AHP, but the method requires an accurate distinction between the values of the decision problem, the included factors, and their intrinsic relationships [35]. The ELECTRE method eliminates inferior solutions by constructing a series of weakly dominant relationships, which sequentially reduce the number of alternatives without affecting the results by considering fewer data [36]. However, this method lacks objective data to help further understand the differences between alternatives and cannot fully utilize the information in the decision problem [37]. In both design and implementation, PROMETHEE is relatively simple [38] and this method has gradually evolved from a single method to include I-VI, PROMETHEE GDSS, PROMETHEE TRI, and other method families. However, it has shortcomings in problem design and weight determination [39] Hwang and Yoon Introduced TOPSIS to specify the most suitable solution based on the nearness degree to the ideal solution [40]. The VIKOR method was developed by Opricovic to solve MCDM problems containing different units and conflicting criteria so as to determine compromise solutions [41]. The last two methods are widely used in MCDM problems; TOPSIS uses vector normalization while VIKOR uses linear normalization, thus the former has higher accuracy [42]. Various studies in the context of MCDM emphasize the use of simple and understandable techniques to deal with MCDM problems and the computations should be simple and easy to perform. From the above, it can be seen that the TOPSIS method is practical in dealing with the MCDM problem compared to the other methods proposed above.

In the evaluation of MCDM, due to the diversity of raw data, the assignment of weight value can be divided into subjective and objective assignment methods [34]. The first is the method in which the decision maker independently assigns values to indicators based on their importance and usually relies on the subjective experience or judgment of people, representing only the decision maker's judgment of the importance of the indicator, which is more subjective and arbitrary. The objective assignment method is that which assigns weights to indicators through scientific calculation algorithms, and is not influenced by the subjective judgment of decision-makers, with the original data being derived from the attributes of the decision scheme [43].

Entropy in information theory is used to quantify the information content of a certain message [44]. The decision matrix for a set of alternatives contains a certain amount of information, so entropy can be used as a tool in weight value evaluation [45]. The entropy and TOPSIS methods are combined into a completely objective decision-making method, where the determination of weights and decision outcomes does not involve any subjective preferences but relies entirely on objective data of alternatives. Previous studies have shown the importance of the entropy weighted TOPSIS method for the study of problems related to development strategies. Huang et al. [46] evaluated the operational performance of urban rail transit systems by the entropy weighted TOPSIS method based on 34 months of initial data from the Chengdu subway. Yu et al. [47] used the entropy weighted TOPSIS method to evaluate industrial wastewater treatment projects. Bhowmik et al. [48] used the entropy weighted TOPSIS method to select the best green energy from multiple alternatives for sustainable planning. Kaynak et al. [49] used the entropy weighted TOPSIS method to evaluate the innovation performance of four EU candidate countries. These show that the entropy TOPSIS method is widely used in various fields.

Currently, China has recognized the need to implement prefabrication in rural areas, but no research provides quantitative models to assist in the development of prefabrication implementation strategies. Governments at all levels need to formulate rural prefabrication implementation policies based on regional development potential, but there is a lack of research aimed at evaluating regional rural prefabrication implementation potential. To fill this gap, this study proposes a method for evaluating regional rural prefabricated implementation potential, aiming to identify political, economic, social, and technological potential problems to better promote regional prefabricated rural housing implementation. The research purpose is to:

1. Determine the evaluation index system of county rural prefabrication implementation potential by PEST analysis and literature analysis;
2. To propose an entropy weighted TOPSIS evaluation method of rural prefabrication implementation potential, by improving the evaluation object and the formula of taking positive and negative ideal solutions, to further match the evaluation results with the real situation.
3. Chongqing Municipality was selected for empirical analysis to analyze the advantages and disadvantages of implementing rural prefabrication in its subordinate counties, which could provide a reference for other regions.

2. Materials and Methods

2.1. Selection of Evaluation Indicators

The selection of evaluation indicators is based on the principles of measurability and easy access to data. Based on a PEST analysis and a literature analysis, the elements affecting the implementation of rural prefabrication are extracted. The evaluation indicator system is constructed in conjunction with China's prefabrication industry. The PEST analysis effectively analyzes macro-environmental factors, where P, E, S, and T represent political, economic, social, and technological factors, respectively [50]. Currently, it is difficult to obtain endogenous factors in China's rural prefabrication industry, so this method understands the macro environment of rural prefabrication implementation by studying external environmental factors. The process used the Google Scholar search engine, with the keywords "prefab", "precast", and "off-site", and filtered the literature for research relevance [16]. By using the principle of measurable indicators and reading the literature 16 indicators affecting the implementation of prefabricated rural housing were extracted from four dimensions, as shown in Table 1, so that the evaluation results genuinely reflect the actual local situation.

The political layer reflects the policy conditions for the implementation of rural prefabrication. As the implementation of rural prefabrication in China is currently government-led, policy information is essential. P1 represents the strength and importance that governments at all levels attach to implementing rural prefabrication. P2 represents the mandatory share of new buildings applying prefabricated technology in government industrial planning documents by county. P3 represents the current implementation of rural prefabrication and P4 represents the practical support for implementing the prefabrication industry in each county.

The economic layer reflects the material basis for developing rural prefabrication in each county. E1 represents the level of economic development of each county, while E2–E4 reflect the capacity of each county to produce prefabricated components. E5 represents the road transport conditions of each county; if the road network is denser, then the rural access rate is higher and the transport cost lower.

Table 1. Indicator system for evaluating the implementation potential of prefabricated rural housing.

Criterion Layer	Indicator Layer	Code	Unit	Property	References
Political	Number of policies to incentivize the construction of prefabricated rural housing	P1	/	+	[51–56]
	Policy targets for the proportion of prefabricated buildings	P2	%	+	[52,54–57]
	Area of the prefabricated rural housing demonstration project	P3	m^2	+	[52,54–56,58]
	Target output value of the prefabricated component	P4	100 million yuan	+	[52,54,56,58–60]
Economic	GDP per capita	E1	Yuan	+	[51,52,59,61]
	Production capacity of prefabricated concrete components	E2	10,000 m^3	+	[51,56,58,62,63]
	Production capacity of prefabricated wall panels	E3	10,000 m^3	+	[51,56,58,62,63]
	Production capacity of prefabricated steel components	E4	10,000 tons	+	[51,56,58,62,63]
	Road network density	E5	/	+	[52,53,55,59,62–64]
Social	Year-end residential completions	S1	10,000 m^2	+	[7,52,55,65]
	Number of rural population	S2	10,000 people	+	[7,52,53,55]
	Disposable income per resident in rural areas	S3	Yuan	+	[7,51–53,55]
Technological	Number of prefabrication industrial bases	T1	/	+	[54,56,58,60,63,64,66,67]
	Number of people working in the construction industry	T2	10,000 people	+	[53,55,59,62,66,67]
	Number of construction general contract enterprises	T3	/	+	[53,56,58,64,65,68]
	Number of construction enterprises	T4	/	+	[53,56,58–60,65,66]

The social layer reflects the current state of the housing market in each county, which is the direct driver of rural prefabrication. S1 represents the housing demand in each county, S2 represents the number of potential consumers of prefabricated rural housing, and S3 represents the level of purchasing power of potential rural consumers.

The technological layer reflects the technological support for the implementation of rural prefabrication. T1 represents the technological conditions of rural prefabrication in each county. T2 represents the number of specialized construction workers in each county. T3 represents the number of leading enterprises in each county in terms of construction technology and scale and T4 represents the degree of perfection of the construction industry chain in each county.

2.2. Entropy Weighted TOPSIS Model

The entropy weighted TOPSIS model is an improvement on the traditional TOPSIS model, where the weights of evaluation indicators are determined by the entropy weighted method, then the ranking of evaluation objects is determined by the TOPSIS model using the method of approximating the ideal solution. The entropy weight method is based on information provided by each evaluation indicator to objectively determine its weight, which not only objectively reflects the importance of a specific indicator in the indicator system at the time of decision making, but also prominently reflects the change in the weight of the indicator over time, and is, therefore, suitable for regional implementation potential evaluation research. The core idea of the TOPSIS method is to define the distance between the optimal and inferior solutions of a decision problem, calculate the relative nearness degree of each evaluation object to the ideal solution, and rank the solutions' superiority. Determining the weights is an essential aspect of the TOPSIS method, and using the information entropy method can effectively eliminate the influence of subjective factors [69]. The main calculation steps of the entropy weighted TOPSIS method follow.

Step 1: Standardize the indicators. The indicators for evaluating the implementation potential of prefabricated rural housing are all positive, with larger values of positive indicators indicating higher potentials of implementation, and smaller values of negative indicators higher implementation potentials. In the event that both positive and negative indicators are present they need to be standardized in a dimensionless way, with the values of the indicators being in the range (0, 1). The standardization formulas are

$$\text{Positive indicators}: \ x_{ij}' = \left(x_{ij} - \min x_{ij}\right) / \left(\max x_{ij} - \min x_{ij}\right) \tag{1}$$

$$\text{Negative indicators}: \ x_{ij}' = \left(\max x_{ij} - x_{ij}\right) / \left(\max x_{ij} - \min x_{ij}\right) \tag{2}$$

where x_{ij} indicates the original value of the evaluation indicator, x_{ij}' is the standard value, and. $\max x_{ij}$ and $\min x_{ij}$ indicate the maximum and minimum values of the jth indicator for ith regions, respectively.

Step 2: H_j is determined as the information entropy value. $\left(1 - H_j\right)$ The greater the information utility value of an indicator, the greater the weight of that indicator in the evaluation and the more critical it is. Where, p_{ij} is the weight of the jth indicator in the ith region.

$$H_j = -\frac{1}{\ln m}\sum_{i=1}^{m} p_{ij} \ln p_{ij} \tag{3}$$

Step 3: Determine the weight of the jth indicator W_j

$$W_j = \left(1 - H_j\right) / \sum_{j=1}^{n}\left(1 - H_j\right) \tag{4}$$

Step 4: Construct a weighted decision matrix V

$$V = w_i * x_{ij}' \tag{5}$$

Step 5: Determine the positive and negative ideal solutions for the indicator. Let V^+ denote the best of all solutions, called the positive ideal solution, and V^- denote the least desirable solution, called the negative ideal solution.

$$V^+ = \left\{\max v_{ij} \middle| i = 1, 2, \cdots, m\right\} \tag{6}$$

$$V^- = \left\{\min v_{ij} \middle| i = 1, 2, \cdots, m\right\} \tag{7}$$

Step 6: The Euclidean distance is calculated. Let the distances of each evaluation object vector to the positive and negative ideal solutions be D^+ and D^-, respectively, then

$$D^+ = \sqrt{\sum_{j=1}^{m}\left(V_{ij} - V_j^+\right)^2}(i = 1, 2, \cdots, n) \tag{8}$$

$$D^- = \sqrt{\sum_{j=1}^{m}\left(V_{ij} - V_j^-\right)^2}(i = 1, 2, \cdots, n) \tag{9}$$

Step 7: Calculate the nearness degree C_j as

$$C_j = \frac{D^-}{D^+ + D^-} \tag{10}$$

The nearness degree indicates how close the rating object is to the positive ideal solution, i.e., the optimal solution, and is expressed by C_j. Obviously, for $C_j \in (0,1)$, the closer C_j is to 1, the closer the implementation potential value of prefabricated rural housing in the region is to the optimal level, and the promotion of prefabricated rural housing can be prioritized; conversely, the closer C_j is to 0, the further the potential implementation value of prefabricated rural housing in the region is to the optimal level, and the promotion of prefabricated rural housing can be carried out after the relevant industrial base is perfected.

2.3. Study Region

Chongqing is located in southwestern China, with 38 counties under its jurisdiction, as shown in Figure 1, a total area of 82,402 square kilometers, and a resident population of 32 million, of which 9.79 million people (30.54%) live in the countryside. As the only municipality directly under the central government in western China, Chongqing has many counties under its jurisdiction, a large rural population, and a typical dual economic structure. Moreover, there are significant differences among counties in terms of economy, geography, and culture. For example, counties in western Chongqing have convenient transportation and good economic development under the radius of Chongqing's urban area; southeastern Chongqing and northeastern Chongqing are relatively backward in economy and industry due to the obstruction of mountains and rivers and poor transportation; southeastern Chongqing is also a region inhabited by China's ethnic minorities.

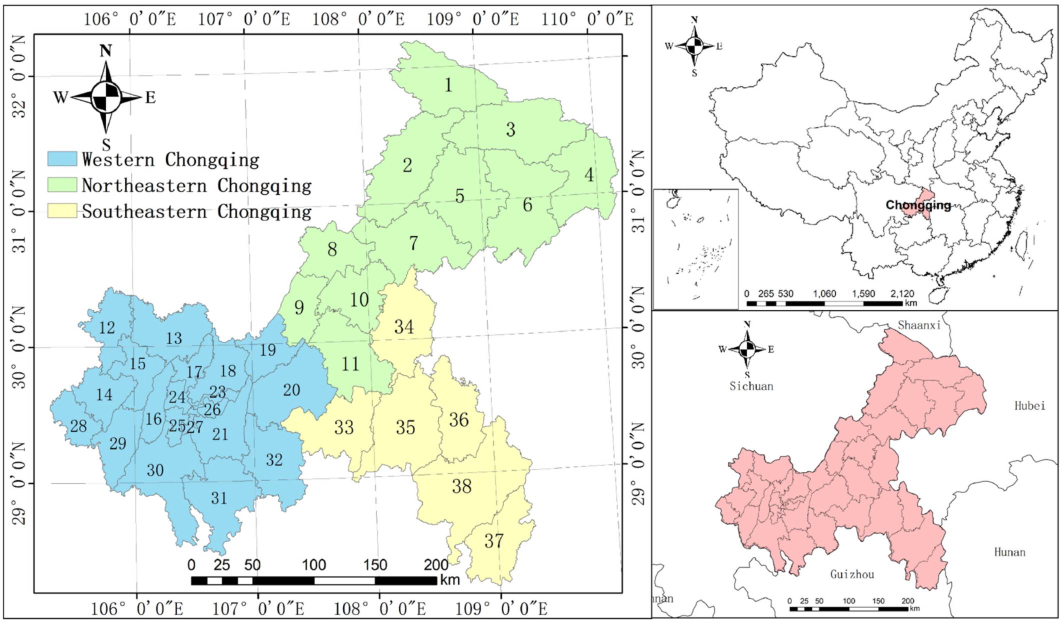

Figure 1. Chongqing Location Map. 1. Chengkou; 2. Kaizhou; 3. Wuxi; 4. Wushan; 5. Yunyang; 6. Fengjie; 7. Wanzhou; 8. Liangping; 9. Dianjiang; 10. Zhongxian; 11. Fengdu; 12. Tongnan; 13. Hechuan; 14. Dazu; 15. Tongliang; 16. Bishan; 17. Beibei; 18. Yubei; 19. Changshou; 20. Fuling; 21. Banan; 22. Yuzhong; 23. Jiangbei; 24. Shapingba; 25. Jiulongpo; 26. Qijiang; 37. Xiushan; 38. Youyang.

Therefore, the villages in Chongqing are complex and can better reflect the characteristics of Chinese villages. Simultaneously, Chongqing has also begun to pay attention to the implementation of prefabricated rural housing, which is the premise for this study being conducted. Therefore, the empirical evidence in this paper takes Chongqing as an example to measure the implementation potential of prefabricated rural housing in 32 of Chongqing's counties, excluding its jurisdictions with an urbanization rate of more than 90%, to provide a reference for the government to develop rural prefabrication implementation strategies.

2.4. Data Sources

The main sources of research data are the Chongqing Statistical Yearbook 2022, Chongqing Government Documents, the "14th Five-Year Plan" for the development of the modern construction industry in Chongqing, the vector data of Chongqing's road network, Chongqing's prefabricated components production enterprise list, and government websites. Except for the statistical yearbook, all data are as of January 2023.

3. Results

3.1. Evaluation Process

The original evaluation index matrix composed of raw data was standardized by Formulas (1) to (2), and then the weights of each evaluation index of the prefabricated implementation potential of Chongqing counties were calculated according to Formulas (3) to (5), and the results are shown in Table 2. Next, the positive and negative ideal solutions were determined according to Formulas (6) to (7). Then the weighted normalized evaluation matrix V is substituted into the Formulas (8) to (9) to derive the distance between the rural prefabricated implementation potential and the positive and negative ideal solutions of 32 counties in Chongqing, the results of which are shown in Table 3. Based on the distance between the prefabricated rural housing implementation potential and the positive and negative ideal solutions of each county in Table 3, the nearness degree of the rural prefabricated implementation potential of 32 counties in Chongqing can be obtained by Formula (10). Meanwhile, the evaluation results of the four evaluation subsystems of political, economic, social, and technological are calculated by the same method, and the final results are shown in Table 4.

The results of the evaluation of the implementation potential in 32 counties are divided into five levels based on the nearness degree: Level I (0.0, 0.2), Level II (0.2, 0.4), Level III (0.4, 0.6), Level IV (0.6, 0.8), and Level V (0.8, 1), as shown in Table 5 and Figure 2. When the nearness degree is closer to 1, the greater the potential for implementing prefabricated rural housing in the county. Based on the values of the overall nearness degree, it can be seen that 28 counties in Chongqing have an overall nearness degree concentrated between 0.0 and 0.4. There are significant difficulties in promoting prefabricated rural housing in Chongqing.

Table 2. The weighting of indicators.

Criterion Layer	Weight	Code	Indicator Layer	Weight
Political	0.4516	P1	Number of policies to incentivize the construction of prefabricated rural housing	0.1246
		P2	Policy targets for the proportion of prefabricated buildings	0.0547
		P3	Area of the prefabricated rural housing demonstration project	0.1817
		P4	The target output value of the prefabricated component	0.0907
Economic	0.3152	E1	GDP per capita	0.0158
		E2	Production capacity of prefabricated concrete components	0.0765
		E3	Production capacity of prefabricated wall panels	0.0858
		E4	Production capacity of prefabricated steel components	0.1117
		E5	Road network density	0.0255
Social	0.0684	S1	Year-end residential completions	0.0389
		S2	Number of rural population	0.0142
		S3	Disposable income per resident in rural areas	0.0152
Technological	0.1648	T1	Number of prefabrication industrial bases	0.0965
		T2	Number of people working in the construction industry	0.0253
		T3	Number of construction general contract enterprises	0.0178
		T4	Number of construction enterprises	0.0252

Table 3. Distance between the potential of rural prefabrication implementation and the positive and negative ideal solutions in 32 counties of Chongqing.

County	D^{+}	D^{-}	County	D^{+}	D^{-}
Beibei	0.2959	0.0713	Kaiju	0.3106	0.0313
Yubei	0.2152	0.1718	Liangping	0.3120	0.0196
Banan	0.2489	0.1494	Chengkou	0.3149	0.0002
Fuling	0.2767	0.0890	Fengdu	0.3071	0.0245
Qijiang	0.2514	0.1589	Dianjiang	0.1862	0.2253
Dazu	0.3044	0.0401	Zhongxian	0.3050	0.0239
Changshou	0.2818	0.0827	Yunyang	0.3073	0.0242
Jiangjin	0.2031	0.1540	Fengjie	0.3068	0.0331
Hechuan	0.2887	0.0682	Wushan	0.3135	0.0086
Yongchuan	0.2479	0.1583	Wushi	0.3141	0.0059
Nanchuan	0.2771	0.0890	Qianjiang	0.3087	0.0301
Bishan	0.2953	0.0640	Wulong	0.3137	0.0103
Tongliang	0.2675	0.0944	Shizhu	0.3137	0.0090
Tongnan	0.2295	0.1114	Xiushan	0.3135	0.0105
Rongchang	0.2287	0.1591	Youyang	0.3142	0.0071
Wanzhou	0.3034	0.0440	Pengshui	0.3137	0.0082

Table 4. Results of the rural prefabrication implementation potential evaluation.

County	Political	Economic	Social	Technological	Comprehensive	Ranking
Dianjiang	0.6365	0.4133	0.5427	0.3758	0.5475	1
Yubei	0.3902	0.6232	0.5691	0.7757	0.4439	2
Jiangjin	0.2985	0.5277	0.8174	0.5893	0.4312	3
Rongchang	0.4248	0.4464	0.4503	0.2807	0.4103	4
Yongchuan	0.2568	0.5143	0.6168	0.6452	0.3897	5
Qijiang	0.1952	0.4968	0.4287	0.5972	0.3872	6
Banan	0.4309	0.3445	0.6199	0.3558	0.3751	7
Tongnan	0.3823	0.2403	0.5093	0.3896	0.3267	8
Tongliang	0.2411	0.3852	0.5311	0.4465	0.2610	9
Fuling	0.2103	0.3837	0.4659	0.6552	0.2434	10
Nanchuan	0.2243	0.2646	0.3280	0.2703	0.2431	11
Changshou	0.1023	0.4933	0.6307	0.1766	0.2268	12
Beibei	0.1866	0.4257	0.4451	0.2098	0.1942	13
Hechuan	0.1232	0.4035	0.6336	0.4032	0.1912	14
Bishan	0.1023	0.4125	0.4697	0.3067	0.1782	15
Wanzhou	0.1036	0.2070	0.5469	0.5070	0.1265	16
Dazu	0.1023	0.3242	0.4929	0.2895	0.1163	17
Fengjie	0.0000	0.1258	0.4715	0.3647	0.0975	18
Kaiju	0.0000	0.1072	0.6302	0.3239	0.0916	19
Qianjiang	0.1036	0.1311	0.2945	0.1566	0.0888	20
Fengdu	0.0708	0.1680	0.3409	0.2090	0.0739	21
Yunyang	0.0000	0.1582	0.4272	0.3234	0.0731	22
Zhong	0.0363	0.1926	0.4189	0.2023	0.0726	23
Liangping	0.0000	0.2404	0.4284	0.1875	0.0592	24
Xiushan	0.0000	0.1666	0.2145	0.1117	0.0323	25
Wulong	0.0000	0.1871	0.2259	0.0618	0.0318	26
Shizhu	0.0000	0.0939	0.2516	0.0979	0.0280	27
Wushan	0.0000	0.0884	0.1940	0.1266	0.0266	28
Pengshui	0.0000	0.0973	0.2346	0.0810	0.0253	29
Youyang	0.0000	0.0289	0.2432	0.0374	0.0222	30
Wushi	0.0000	0.0177	0.1089	0.1218	0.0184	31
Chengkou	0.0000	0.0000	0.0076	0.0000	0.0006	32

Table 5. Grading of evaluation results.

Value Range	Status	Level	Feature Description
0 < H < 0.2	worse	I	The level of implementation potential of rural prefabrication is extremely low and not suited to the promotion of prefabricated rural housing.
0.2 ≤ H < 0.4	bad	II	The level of implementation potential of rural prefabrication is low and barely suited to the promotion of prefabricated rural housing.
0.4 ≤ H < 0.6	normal	III	The level of implementation potential of rural prefabrication is general and basically suited to the promotion of prefabricated rural housing.
0.6 ≤ H < 0.8	good	IV	The level of implementation potential of rural prefabrication is good and more suited to the promotion of prefabricated rural housing.
0.8 ≤ H < 1.0	excellent	V	The level of implementation potential of rural prefabrication is very high and well suited to the promotion of prefabricated rural housing.

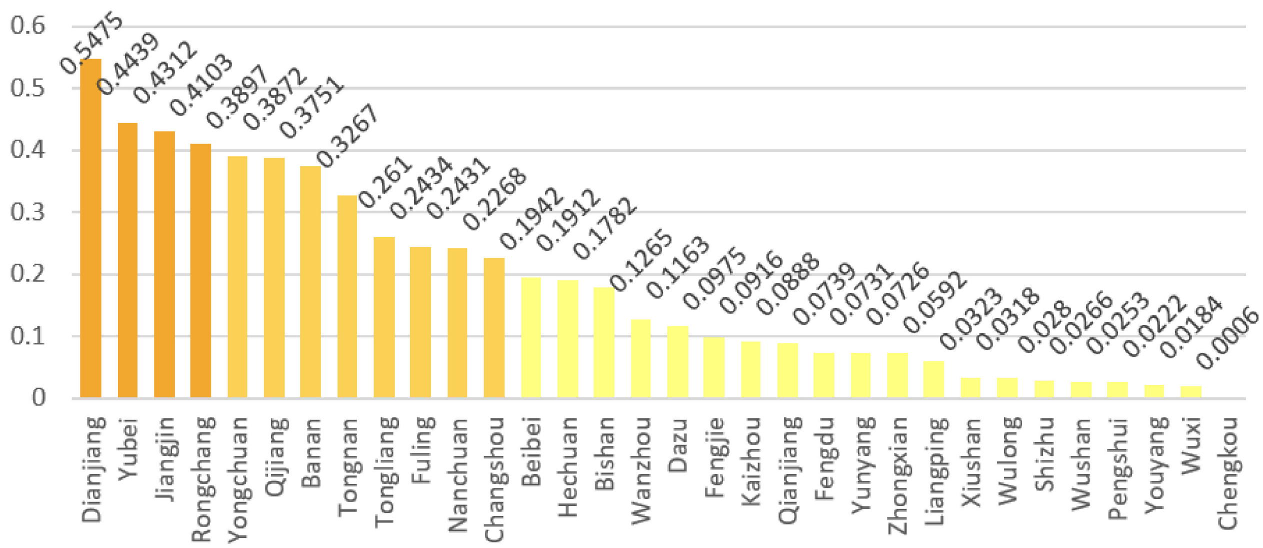

Figure 2. Ranking the comprehensive implementation potential of prefabricated rural housing in Chongqing by county.

ArcGIS was used to visualize the evaluation results to visually reflect the implementation potential of prefabricated rural housing in Chongqing, resulting in Figures 3 and 4.

3.2. Analysis of Comprehensive Implementation Potential Evaluation Results

Figure 3 shows the comprehensive evaluation results. There are 28 counties in Chongqing with comprehensive nearness degrees concentrated in (0.0, 0.4). This indicates great difficulties in implementing prefabricated rural housing in Chongqing as a whole. The potential of rural prefabricated implementation in Dianjiang, Yubei, Jiangjin, and Rongchang is at Level III, which meets the basic conditions for implementing prefabricated rural housing. Yongchuan, Qijiang, Banan, Tongnan, Tongliang, Fuling Nanchuan, and Changshou show and implementation potential at Level II and have the relative possibility of implementing prefabricated rural housing in Chongqing. The other 20 counties have the potential of implementing prefabricated rural housing below 0.2, and the development foundation is weak and not suitable for implementing prefabricated rural housing. In summary, some counties in western Chongqing have the possibility of implementing prefabricated rural housing due to their good economic and construction industry foundation.

Only Dianjiang in northeastern and southeastern Chongqing can implement prefabricated rural housing.

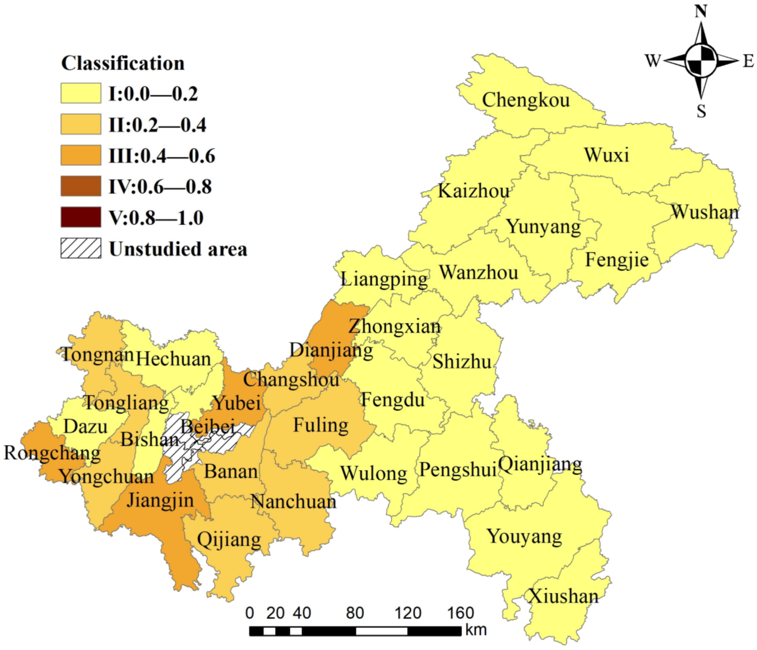

Figure 3. Results of the comprehensive evaluation of the implementation potential of prefabricated rural housing in Chongqing.

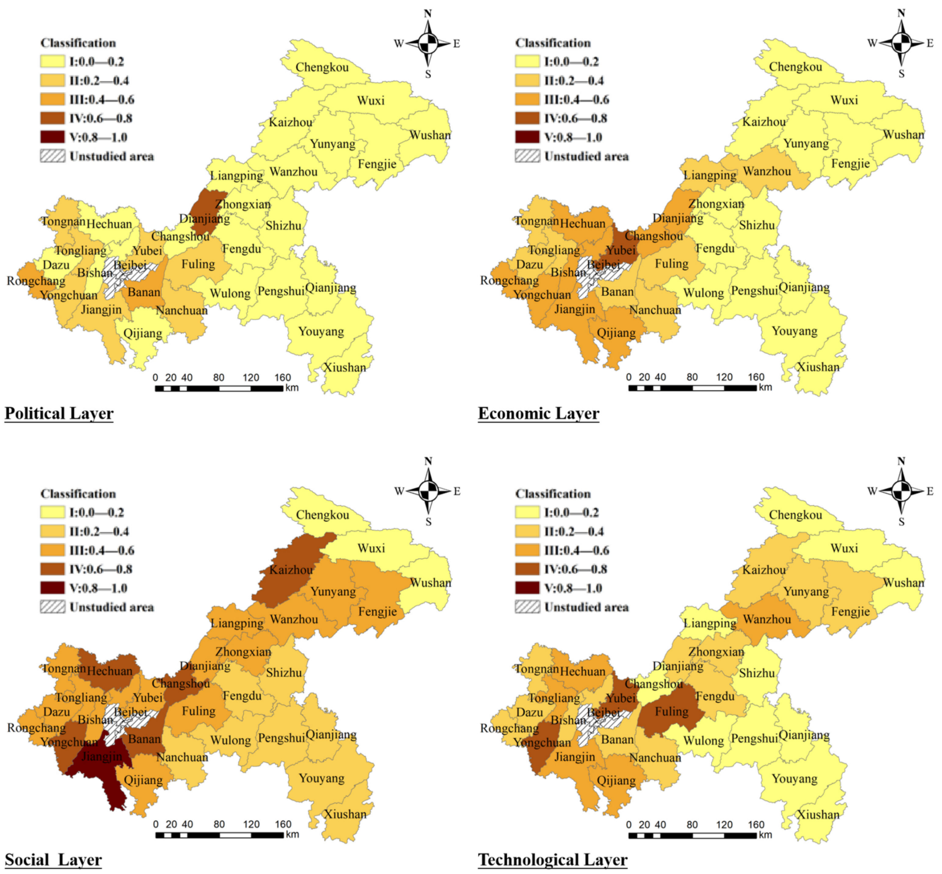

Figure 4. Results of the subsystem evaluation of the implementation potential of prefabricated rural housing in Chongqing.

3.3. Analysis of Subsystem Evaluation Results

Figure 4 shows the evaluation results of each subsystem. The evaluation results of the political level subsystem show that Dianjiang is located at Level IV, and Banan and Rongchang are located at Level III with relative policy advantages. In 2022, Chongqing subsidized RMB 500/m^2 and RMB 200/m^2 for new prefabricated rural houses for self-occupation or business, respectively. Under the policy guidance, Dianjiang, Tongnan, Rongchang, Jiangjin, and Banan have taken the lead in the construction of prefabricated rural housing demonstration projects. At the same time, Chongqing Municipality clarifies the proportion of prefabricated buildings to new buildings in each county: 20–25% in western Chongqing, 15–20% in northeastern Chongqing, and 15% in southeastern Chongqing. Banan, Rongchang, and Tongnan issued policies requiring the active promotion of green building materials applications and PC methods in rural areas. The policies of each county regarding the implementation of rural prefabrication are reflected in the evaluation results of the political layer subsystem.

The evaluation results of the economic layer subsystem show that the overall potential of western Chongqing is high. There are 61 prefabricated component production factories in Chongqing, involving the production of prefabricated concrete components, steel components, and new wall panel components, which are concentrated in western Chongqing and the counties adjacent to western Chongqing. This shows that areas with a high level of regional economic development and dense road networks attract more prefabricated enterprises to invest and set up factories, which will galvanize the development of local prefabricated rural houses.

The evaluation results of the social layer subsystem show that there is a significant rural housing demand in western and northeastern Chongqing (except in Chengkou, Wuxi, and Wushan counties). In contrast, Chengkou, Wuxi, and Wushan counties in southeast and northeastern Chongqing have weaker economic bases, the villagers have lower disposable income, and there is less new housing demand. The high cost of prefabricated rural houses creates difficulties in implementation for Chengkou, Wuxi, and Wushan counties.

The evaluation results of the technological layer subsystem show that the technological conditions for the promotion of prefabricated rural housing in western Chongqing are significantly better than those in northeastern and southeastern Chongqing. The 30 prefabricated industry bases in Chongqing are all located in western Chongqing, which could provide technological and workforce support for the implementation of rural prefabrication. Wanzhou, as the central county of northeastern Chongqing, has a relative advantage in the technical dimension of implementing prefabricated rural housing due to a large number of construction general contractors and construction enterprises.

4. Discussion

4.1. Empirical Findings

The weighting of the indicators in the evaluation system for the implementation potential of prefabricated rural housing is 0.4516, 0.3152, 0.0684, and 0.1648 for the political, economic, social, and technological subsystems, respectively, and the sum of the weighting of the political and economic subsystems is over 0.76. The potential for implementing prefabricated rural housing in Chongqing is closely related to policy orientation and the foundation of industrialization. The sum of the weights of the P1 and P3 indicators in the political subsystem is 0.3, which corresponds to the number of policies to incentivize the construction of prefabricated rural housing and the area of demonstration projects for prefabricated rural housing; the sum of the weights of the E2, E3, and E4 indicators in the economic subsystem is 0.28, which corresponds to the capacity of various prefabricated components. In summary, the announcement of policies related to prefabricated rural housing and the construction of prefabricated rural housing demonstration projects could promote the implementation of prefabricated rural housing in the region. At the same time, good prefabricated component plant capacity is the basis for promoting prefabricated rural housing in the region.

It can be seen from the results of the implementation potential of prefabricated rural housing in Chongqing that the potential for implementing prefabricated rural housing in western Chongqing is significantly higher than that of other regions, due to their relatively good economic and construction industrialization base and with the support of relevant policies. In contrast, northeastern and southeastern Chongqing (except Dianjiang) are disadvantaged in implementing prefabricated rural housing due to their insufficient policy efforts, weak economic base, and lack of technological support. The implementation potential of each region in Chongqing is ranked as follows: Western Chongqing >> Northeastern Chongqing > Southeastern Chongqing. The counties that should be prioritized for implementation are Dianjiang, Yubei, Jiangjin, and Rongchang.

4.2. Countermeasures and Suggestions

Previous studies on prefabricated building promotion strategies coincide in recognizing the necessity of government macro policies, which is also in line with the logic of this study to construct an evaluation index system for the potential of rural prefabrication implementation using PEST analysis. For example, Correia et al. [70] argued that government policy is the main driver of promoting prefabrication technology. Du et al. [71] argued that incentive policies and uniform industry standards are necessary to promote housing industrialization. Xue et al. [72] suggested that the government should increase the proportion of prefabrication in public projects and extend the pilot experience to other projects. The government should also promote communication among relevant stakeholders to achieve cost reduction.

Scholars have also provided insight into the economic, social, and technological means of implementing prefabricated buildings. From an economic perspective, some scholars suggested that introducing a competition mechanism into the PC market could effectively improve the quality of prefabricated buildings and reduce construction costs. For example, Lou et al. [73] suggested that expanding the number of component factories and improving the PC chain are beneficial to achieve fine management of PC. Chiang et al. [58] argued that the technology of prefabricated construction contracting firms must be valuable, rare, not completely limited, and irreplaceable to be a source of sustainable competitive advantage. From a social perspective, Moradibistouni et al. [74] argued that key to the promotion of prefabricated buildings is the attitude of potential users, which requires government investment and the construction of a large number of high-quality prefabricated demonstration projects. From a technical perspective, Lou et al. [73] proposed to improve technology in the prefabricated building industry by combining BIM technology. Mao et al. [75] argued that the improvement of component production capacity and technology level is an effective way to reduce costs in prefabricated buildings. Jiang et al. [54] argued that the government needs to develop unified technical standards, train skilled workers, and foster technology pioneer companies in government-led projects. Chang et al. [65] argued that there are few sunk cost barriers in China's emerging prefabrication industry and that new prefabrication factories should adopt high-performance green technologies and equipment, as well as cultivate a stable and skilled workforce. Furthermore, the contracting model of projects should be optimized to enhance collaboration in all phases of prefabricated construction.

Combining the results of previous research and empirical analysis, considering the differences between prefabricated rural and prefabricated urban buildings, the following countermeasures and suggestions are proposed for the implementation of prefabricated rural housing in Chongqing.

Political Dimension: Adopt mandatory policies to stipulate the proportion of prefabrication in rural demonstration projects and develop uniform and feasible technical and industry standards to guide residential construction. Adopt incentive policies to reduce the construction burden of farmers and attract corporate investment. Counties with a good industrial base located in western Chongqing are given priority to implement prefabricated rural housing construction. Other counties can adopt prefabricated technology in the renovation of rural houses to improve the life cycle of houses and gradually realize the industrialization of rural housing.

Economic Dimension: At present, there are 61 prefabricated building component manufacturing enterprises in Chongqing, of which 52 are located in western Chongqing, 9 in northeastern Chongqing, and 0 in southeastern Chongqing. It could take the lead in building prefabricated rural housing industry chains in western Chongqing, cultivate general contracting enterprises, and form good market competition. Dianjiang and Wanzhou in northeast Chongqing could arrange prefabricated rural housing industry bases to attract the construction of prefabricated component factories and optimize the construction cost of prefabricated rural housing. Southeastern Chongqing does not have the conditions for the development of rural residential industrialization for the time being.

Social Dimension: In the context of China's rural revitalization, villagers' living standards are increasingly improving and they are actively seeking a better quality environment. Chongqing's huge rural population base creates a massive rural construction market. The government can use prefabricated technology in rural public projects and housing construction to enhance villagers' understanding and recognition of prefabricated housing.

Technological Dimension: The government could set design selection standards for prefabricated rural housing, organize a special technical demonstration, promote the use of BIM technology, and cultivate prefabricated industry bases to promote technical exchanges; at the same time, strengthen technical training for rural grassroots builders, blending regional construction experience with prefabricated technology, and achieve increased rural employment opportunities while building prefabricated livable rural houses with regional characteristics.

4.3. Suggestions for Future Research

This study focuses on an approach based on objective means to solve evaluation problems and validates its effectiveness with case studies. Although the entropy weighted TOPSIS model has been successfully applied to a large number of cases, it also has limitations. For example, the evaluation system needs to be established by selecting quantitative indicators; the results of indicator weights are territorial; and the weights can be affected significantly when the dispersion of indicator data is too high. The development of MCDM methods is getting faster and faster at present. The emergence of new methods is expected to provide more reliable analysis results. The ordinal priority approach (OPA), for example, is a novel and potential alternative. The OPA is an emerging MCDM method proposed by Ataei et al. in 2020 [76]. This method is based on linear programming and ordinal relations to solve MCDM problems and is currently considered an effective, objective, and flexible method. The significant advantage of this method is that it does not require a standardization process, pairwise comparison, and data integrity. For instance, the OPA does not make use of a pairwise comparison matrix, decision-making matrix (no need for numerical input), normalization methods, and averaging methods for aggregating the opinions of experts (in group decision making) [77]. The current related research extends OPA, for example, Mahmoudi et al. [77] proposed OPA for Fuzzy Linguistic Information (OPA-F), which has extended its applicability to problems containing linguistic information. Mahmoudi et al. [78] also proposed the Grey Ordinal Priority Approach (OPA-G), showing that it can work without any linguistic variable or pairwise comparison-based data and has a high capability of dealing with greyness/uncertainty. Mahmoudi et al. [79] also proposed the Robust Ordinal Priority Approach (OPA-R), which can detect and decrease subjectivity in experts' opinions; calculate the weights of the experts, criteria, and projects associated with the most robust scenario.

On the other hand, previous research results provide a macro-strategic reference for the initial implementation of prefabricated rural housing in the region, and the shortcomings exposed by its subsystem evaluation (PEST) deserve further study. The entropy weighted TOPSIS model can be combined with grey relation analysis in the methodology. Grey relation analysis is a method for quantitative description and comparison of the development of a system and, using this method, the degree of influence of each sub-series on the parent series can be analyzed [80]. Therefore, using grey relation analysis can find the degree of relation between each subsystem and the parent system, analyze the potential influence of internal subsystems on the implementation of prefabricated rural housing by the magnitude of the relation, and conduct an internal horizontal evaluation of the evaluation system.

5. Conclusions

Rural prefabrication implementation in China has just started, and there is a lack of research to evaluate the potential of rural prefabrication implementation in counties. To address this research gap, this study proposes an evaluation method for the potential of rural prefabrication implementation in counties. Through a systematic review of previous studies on the evaluation of regional construction industrialization development, this study identifies 16 evaluation indicators in four dimensions: political, economic, social, and technological, and uses the entropy weighted TOPSIS model for indicator assignment and case empirical evidence to provide strategies and suggestions for rural prefabrication implementation in Chongqing.

The entropy weighted TOPSIS model overcomes the bias caused by personal factors in previous subjective assignment methods and reflects the difference between the potential of the evaluation object and the ideal level. The entropy weighted TOPSIS model also shows that the indicator weights are not static and will change not only with the evaluation region but also with the development of the industry. However, this paper is not fully developed in terms of indicator selection and evaluation system construction due to the influence of data accessibility, so the evaluation study on the implementation potential of county rural prefabrication still has some limitations. Chongqing, as the city with the largest number of counties under its jurisdiction in China, has uneven development across regions and is therefore typical. Choosing Chongqing as a research case allows us to judge the rationality and validity of the evaluation system. However, at the same time, because different cities are in different development stages and social environments, some indicators may differ to some extent between cities and countries. Therefore, it is valuable to continue to deepen the universality of the evaluation system and evaluation methods.

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