

Application Feasibility and Optimization Scheme of Modular Building in Multiple Fields

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Abstract. Against the backdrop of the green transformation and high-quality development of the construction industry, modular construction has gradually become a key development direction of the modern construction sector due to its inherent intensive and efficient characteristics. This study takes 8 locations across 5 cities in Yunnan Province and Yanhekou Village, Mentougou District, Beijing as the research areas. We conducted on-site visits to 7 modular construction projects, in-depth interviews with 186 relevant stakeholders, and collected 812 valid questionnaires. Using the multinomial logistic regression model, this paper systematically analyzes the application effects and influencing factors of modular construction. The results show that modular construction has significant advantages in construction efficiency, cost control, low-carbon performance and environmental protection, and enjoys high acceptance among different groups. Meanwhile, aiming at the existing problems in prefabricated construction such as operation and maintenance difficulties and poor cultural adaptation, this study puts forward targeted optimization suggestions, which provide empirical support and practical reference for the large-scale promotion of modular construction.

Keywords: Modular construction; multinomial logistic regression; influencing factors; construction efficiency; low-carbon performance.

1. Introduction

With the intensive support of policies such as the National Rural Revitalization Strategy and the "Dual Carbon Goal", the prefabricated building industry has ushered in a period of rapid development [1]. The market size of prefabricated buildings in China will reach about 200 billion yuan in 2023 and exceed 300 billion yuan in 2025 [2]. However, existing research focuses on a single application scenario, resulting in the comprehensive promotion of modular buildings facing the dilemma of insufficient theoretical support [3-5]. At the same time, there are many shortcomings in the traditional construction model in the above scenarios, such as long construction period and poor cultural adaptability in the field of rural tourism, the urgent need for efficient and safe buildings for post-disaster reconstruction is difficult to meet, and rural housing generally has pain points such as single function and insufficient seismic and moisture-proof performance, and the traditional construction method is high consumption and low efficiency, and the emission of construction waste is large, which is contrary to the concept of low-carbon development [6,7]. The application feasibility study of modular buildings in multiple fields has both important theoretical and practical significance and can enrich the empirical research system of multi-scenario applications of modular buildings at the theoretical level and quantify its feasibility and influencing factors. At the practical level, it can provide replicable solutions for multiple fields and help the industry optimize and upgrade. Based on this, this study selects typical projects such as Changsheng Village and Panxi Village in Yunnan Province and Yanhekou Village in Beijing to explore the application feasibility and core advantages of modular buildings in three major fields through questionnaire surveys, in-depth interviews, field observations, and the research method of disordered multi-classification logistic regression model [8].

2. Study design and case profile

2.1. Research methods and data sources

This study uses a variety of research methods to ensure the authenticity of the data and the scientific nature of the analysis. The first is the case analysis method, which selects the benchmark projects of three typical scenarios of rural cultural tourism, human settlements optimization and post-disaster reconstruction; The second is the field research method, through field visits to 7 projects in 8 places in 5 cities in Yunnan, and in-depth interviews with 186 practitioners and villager representatives; The third is the questionnaire survey method, which distributes questionnaires to residents and tourists in the survey area, and collects 812 valid questionnaires to provide data support for quantitative analysis; Fourth, quantitative analysis uses descriptive statistics and disordered multi-classification logistic regression model to explore the core influencing factors of modular building acceptance.

2.2. Overview of typical cases

Taking into account the differences of regions, ethnicities, and application scenarios, this study selects three typical projects for analysis: The first case is the rural cultural tourism project in Changsheng Village, Shangri-La, Yunnan. The village is a Tibetan village, relying on the tourism resources of the Tiger Leaping Gorge Scenic Area, and transforming the homestay cluster with the model of "light steel keel reconstruction + Tibetan pattern embedding + photovoltaic technology integration", the occupancy rate of the homestay after the transformation reached 85%, and each family will earn an additional 120,000 yuan a year, verifying the economic value of modular buildings in rural cultural tourism scenes. There were 142 valid questionnaires in this survey, of which the comprehensive evaluation of the survey results will be standardized and statistical data. After processing, it is shown in the Fig. 1.

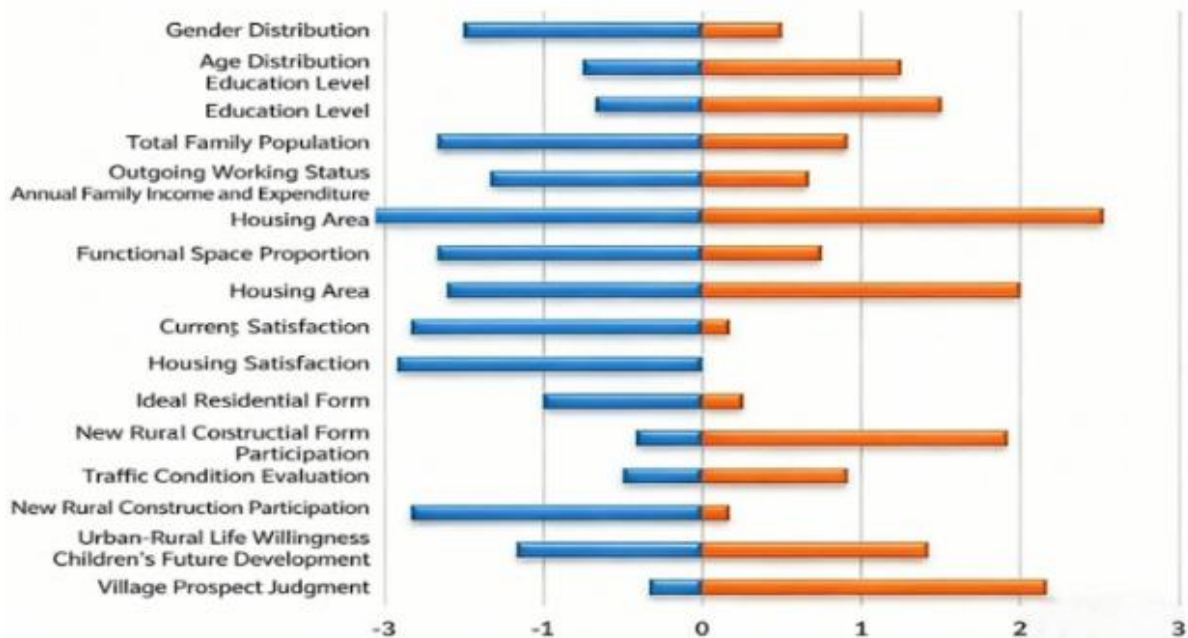


Figure 1. Statistical chart of Changsheng Village survey results. (Photo credit: Original).

Case 2 is the rural housing optimization project in Panxi Village, Dali, Yunnan. Through the transformation path of "seismic reinforcement-functional reconstruction-cultural embedding", after the modular transformation, each family's income increased by 60,000 yuan per year, and the villagers' satisfaction with the cultural integration design reached 82%. The survey results (Fig.2) reflect the needs of the villagers for public service facilities and suggestions for improvement.

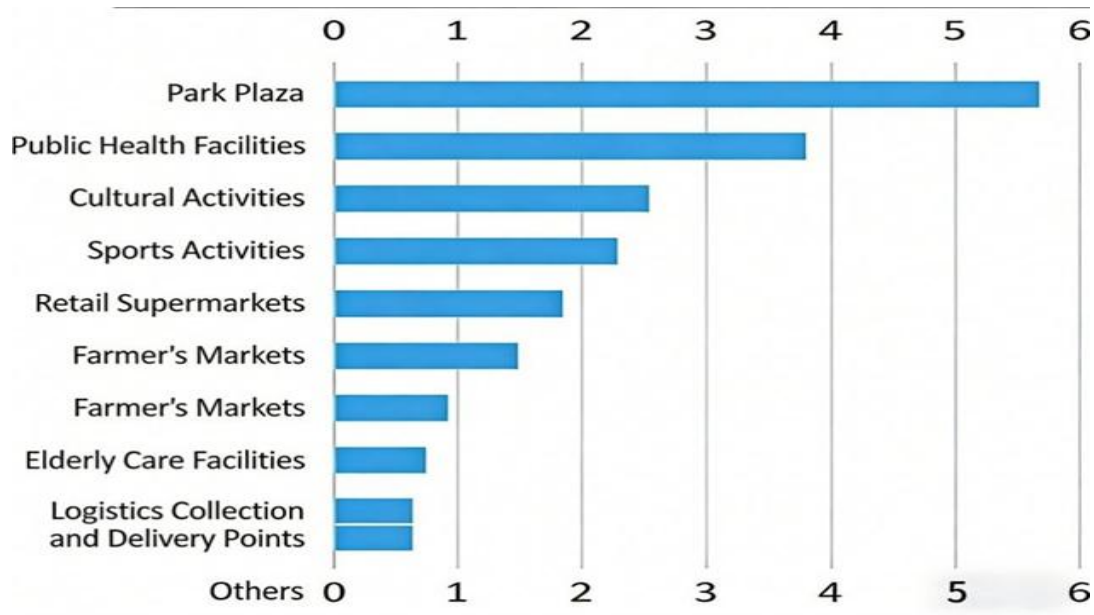


Fig. 2. Panxi Village research suggestion map. (Photo credit : Original).

The third case is the post-disaster reconstruction project of Yanhekou Village in Mentougou District, Beijing. The village will be severely damaged by heavy rains in 2023, and the whole village will be rebuilt with fully assembled modular houses, completing the installation of the main structure of 96 households in just 30 days, reducing labor costs by 40%, reducing carbon emissions by 65%, and integrating into the design for the elderly, and 90% of the villagers recognize its functionality and safety.

3. Quantitative analysis of research data

Based on the first-hand data obtained from the survey, this chapter systematically analyzes the audience acceptance, core influencing factors, and mechanisms of modular architecture in rural scenarios through descriptive statistics, reliability and validity testing, and disordered multi-classification Logistic regression models [8, 9], so as to provide quantitative support for subsequent feasibility demonstration and optimization strategies.

3.1. Research hypothesis and variable setting

3.1.1. Research hypotheses

Based on the information I've gathered, this study proposes two core research hypotheses: tourist accommodation demand and villager acceptance:

H1: Crowd characteristics have a significant impact on tourists' demand for modular cultural and tourism accommodations. H2: Tourists' demand for modular cultural and tourism accommodations is influenced by their travel behavior patterns. H3: Tourists' perceived satisfaction has a significant positive impact on the demand for prefabricated cultural tourism accommodation. H4: The acceptance of modular housing among villagers is influenced by demographic characteristics, family economic status, and cultural identity.

3.1.2. Variable setting

The core explanatory variables of this study are the demand for prefabricated cultural tourism accommodation and the acceptance of prefabricated buildings by villagers, and the core explanatory variables are divided into three dimensions: demographic characteristics, tourism behaviour characteristics, and tourists' perceived satisfaction, and the specific definitions and assignment methods are as follows.

1) Explained variables: Tourists' prefabricated cultural tourism accommodation needs: through the question "Are you willing to choose a prefabricated building to stay in Changsheng Village?" "Measure, the options are set to 1=unwilling, 2=dependent, 3=willing, for Mult categorical variables. Acceptance of prefabricated buildings by villagers: Through the question "Are you willing to choose prefabricated buildings for residential renovation or new construction?" "Measure, the options are set to 1=unwilling, 2=unsure, 3=willing, for Mult categorical variables.

2) Explanatory variables: Demographic characteristics: Four categorical variables were selected, namely gender, age, household registration, and education level, and the dummy variables were assigned, as shown in Table 1. Characteristics of tourism behavior: three classification variables, namely travel frequency, per capita consumption of tourists, and travel mode, were selected to assign virtual variables, as shown in Table 1. Perceived satisfaction of tourists: four continuous variables of catering satisfaction, accommodation satisfaction, tour satisfaction, and infrastructure satisfaction were selected, and measured on a Likert 5-level scale (1=very dissatisfied, 5=very satisfied), and the mean of the corresponding items in each dimension was used as the variable value, and the specific measurement items were shown in Table 2.

Table 1. Categorical variable definition and assignment table.

Variable type	Variable name	Variable definition and assignment
Demographic characteristics	Gender	1=male; 2=Female (reference group)
/	Age	1=30 years old and below; 2=31-45 years old; 3=45 years (reference group)
/	Household registration	1=town; 2=Rural (reference group)
/	Educational level	1=bachelor's degree or above; 2=junior college; 3=High school and below (reference group)
Characteristics of tourism behavior	Frequency of travel	1=3 trips per year $\geq$ 2=1-2 trips per year; 3=1 trip < per year (reference group)
/	per capita consumption of tourism	1= $\geq$ 300 yuan; 2=200-300 yuan; 3=100-200 yuan; 4=< 100 yuan (reference group)
/	Travel mode	1=Self-driving tour; 2=Non-self-driving tour (reference group)

Table 2. Satisfaction dimension measurement item list.

variable	Specific measurement items
Food and beverage satisfaction	Price, deliciousness of dishes, hotel hygiene, facility decoration, service skills
Accommodation satisfaction	Accommodation prices, accommodation hygiene, facility perfection, and service level
Tour satisfaction	Scenic spot ticket price, landscape viewing value, tour guide service level, and tourism product quality
Infrastructure satisfaction	Traffic, public toilets, security, tourism supervision and complaints

3.2. Model selection

In this study, a disordered multi-classification logistic regression model was selected to carry out empirical analysis. The model is suitable for scenarios where the dependent variables are multi-categorized and do not meet the parallel line hypothesis, and two regression equations of "unwilling vs. willing" and "dependent vs. willing" are constructed respectively with "willing to stay" as the reference group, and the regression coefficients are calculated by the maximum likelihood estimation method to analyze the direction and degree of influence of each variable on accommodation demand. The model's calculation uses Formula 1[10]:

$$\ln\left(\frac{p_i}{p_m}\right) = \beta_0 + \sum_{j=1}^n \beta_j x_j \quad (1)$$

p_i represents the probability that tourists choose "unwilling" or "uncertain" options, p_m represents the probability that tourists choose the reference group "willing" option, which satisfies $P_1+P_2+P_3=1$; β_0 is the constant term of the model, n is the number of independent variables included in the model, β_j is the regression coefficient of the independent variable x_j , which is used to measure the direction and intensity of the influence of the independent variable on the explained variable; $Exp(\beta_j)$ is the occurrence ratio, which represents the change multiple of the event occurrence odds ratio for each unit change of the independent variable.

3.3. Model fitting and regression results were analyzed

3.3.1. Overall fit test of the model

After all independent variables were included in the disordered multi-classification logistic regression model [11], the overall fitting effect of the model was first tested. The results show that the overall significance level of the model is $P=0.000<0.01$ indicates that the overall height of the model is significant. The McFadden pseudo- R^2 is 0.356, which shows that the model has good explanatory power for tourists' accommodation needs, and the model fitting effect is excellent. The likelihood ratio test results of each variable are shown in Table 3, in which gender, age, education level, per capita tourism consumption and travel mode all passed the 1% level significance test, tour satisfaction passed the significance test of 5%, travel frequency and infrastructure satisfaction passed the significance test of 10%, and household registration, catering satisfaction, and accommodation satisfaction did not pass the significance test.

3.3.2. The regression results are interpreted in detail

Based on the estimation results of model parameters (as shown in table 4), this study interprets the influence effects of each variable in detail by dimension, and the core conclusions are as follows: Demographic characteristics: H1 basic verification, gender, age, and education significantly affect the acceptance of prefabricated accommodation, male, young and middle-aged people, and highly educated groups have higher acceptance, and household registration has no significant effect. Tourism behavior: H2 is fully verified, and the demand for prefabricated accommodation for high-frequency travel, high-consumption, and non-self-driving tourists is significantly stronger. Perceived satisfaction: H3 part verification, only the scenic spot tour experience and infrastructure perfection positively drive the willingness to stay, catering and basic accommodation services have no significant impact, and the core competitiveness of prefabricated accommodation comes from the integration of culture and tourism and supporting upgrades.

3.4. The core conclusions of empirical analysis

The conclusion is divided into three aspects: first, the core audience of prefabricated cultural tourism accommodation is young, highly educated, high-frequency travel, high-consumption non-self-driving tourists, which is the core goal of marketing promotion; second, the core driving force for tourists to choose prefabricated accommodation is the scenic tour experience and infrastructure perfection, rather than the basic conditions of the accommodation itself; Third, prefabricated buildings have significant market potential in rural cultural tourism scenes, and nearly half of tourists belong to potential conversion groups, which can effectively activate this part of the market demand through targeted product design and scene integration. Based on the full-sample survey data, the three major application scenarios verify the application effectiveness of modular buildings. The cost of renovation is only 30%-50% of traditional reconstruction, the material loss rate has been reduced from 15% to 5%, the transformation of cultural tourism scenes can achieve an average annual income increase of 6-120,000 yuan, and the satisfaction of villagers with cultural integration transformation generally exceeds 75%.

Table 3. Independent variable likelihood ratio test results table.

Variable classification	Variable name	-2x logarithmic likelihood value	Chi-square value	Degrees of freedom df	Significance level P
Intercept	—	174.064 ^a	0.000	0	—
Demographic characteristics	Gender	184.673	10.609	2	0.005(***)
/	Age	187.559	13.495	4	0.009(***)
/	Household registration	177.424	3.361	2	0.186
/	Educational level	191.394	17.330	4	0.002(***)
Characteristics of tourism behavior	Frequency of travel	181.836	7.772	4	0.100(*)
/	per capita consumption of tourism	205.369	31.305	6	0.000(***)
/	Travel mode	186.144	12.081	2	0.002(***)
Tourist perceived satisfaction	Food and beverage satisfaction	174.546	0.482	2	0.786
/	Accommodation satisfaction	174.243	0.179	2	0.914
/	Tour satisfaction	180.618	6.554	2	0.038(**)
/	Infrastructure satisfaction	179.213	5.149	2	0.076(*)

Note: *, **, and *** represent significant at the statistical level of 10%, 5%, and 1%, respectively.

Table 4. Parameter estimation results of disordered multi-classification Logistic regression model.

Variable classification	Variable name	Unwilling to stay overnight (vs. willing to stay)	/	It depends (vs. willing to stay)	/
/	/	Regression coefficient B	Exp(B)	Regression coefficient B	Exp(B)
Intercept	—	3.923(***)	—	6.578(***)	—
Demographic characteristics	Gender (Male vs Female)	-2.034(***)	0.007	-1.958(***)	0.141
/	Age (30 years and under vs over 45 years)	0.026	1.026	-0.287	0.750
/	Age (31-45 years old vs over 45 years old)	-2.646(***)	0.071	-1.097	0.334
/	Household registration (urban vs rural)	-0.428	0.655	0.838	2.311
/	Education level (bachelor's degree or above vs high school and below)	-2.499(***)	0.082	-1.894(**)	0.150
/	Education (junior college vs high school and below)	-1.752	0.201	1.222(*)	3.394
Characteristics of tourism behavior	Frequency of trips (3 times a year $\geq$ vs. < 1 time a year)	2.185(**)	8.887	0.707	2.027
/	Frequency of trips (3 times a year vs 1 time a year)	1.424(*)	4.155	0.719	2.052

/	Per capita consumption of tourists (≥300yuan vs< 100 yuan)	4.587(***)	98.214	-0.051	0.950
/	Per capita consumption of tourism (200-300yuan vs< 100 yuan)	3.836(***)	46.360	0.303	1.354
/	Per capita consumption of tourism (100-200yuan vs< 100 yuan)	3.236(**)	25.428	0.471	1.601
/	Travel mode (self-driving tour vs. non-self-driving tour)	0.033	1.033	0.087	1.091
Tourist perceived satisfaction	Tourist perceived	1.327	3.769	0.283	1.327
/	Accommodation	0.221	1.248	-0.113	0.893
/	tour	-0.583(*)	0.558	-2.636(***)	0.072
/	infrastructure	-1.598(*)	0.202	-0.552	0.576

Note: *, **, and *** represent significant at the statistical level of 10%, 5%, and 1%, respectively.

4. Apply feasibility and optimization strategies

4.1. Application feasibility

Modular buildings are fully feasible for multi-scenario application in rural areas: At the policy level, the development and application of modular buildings are highly consistent with the relevant policy requirements of the national rural revitalization strategy and the "dual carbon" goal, and can obtain policy support and guidance in the process of promotion and application; At the technical level, the technical system of factory prefabrication and on-site assembly is mature, which can adapt to complex construction scenarios, and Building Information Modeling (BIM) technology and parametric design can realize the standardized translation of national cultural elements. At the market level, more than 60% of the target groups in all three scenarios belong to the recipient group or potential conversion group, and there are no fundamental barriers at the market level [6].

4.2. Optimize your strategy

In view of the problems found in the survey, such as shallow cultural adaptation, lack of operation and maintenance system, differentiation of villagers' acceptance, and insufficient full-cycle control, three major optimization directions are proposed: The first is to deepen the localized adaptation design. Establish a digital translation mechanism for national cultural symbols, formulate a list of regional architectural taboos, and optimize the seismic resistance, thermal insulation, and moisture-proof performance of modular structures according to different climate and terrain conditions. The second is to promote cost optimization and the improvement of the operation and maintenance system. Establish a regional supply chain system to reduce logistics costs, promote low-cost transformation technologies such as light steel keel sandwiches, and strive for special subsidies for green buildings. Carry out skills training, cultivate local operation and maintenance teams, and establish a full life cycle traceability system for components. The third is to improve the diversified and collaborative promotion mechanism. build a benefit-sharing mechanism for villagers through income dividends, etc., and use model house experience to eliminate technical concerns and improve villagers' participation; Build a digital operation platform, combine cultural tourism data to dynamically optimize the functional layout of modules, and maximize the comprehensive benefits of the project.

5. Conclusion

Through multi-case empirical and quantitative analysis, this study confirms that modular buildings have full application feasibility in the three major fields of rural cultural tourism construction, human settlement optimization, and post-disaster reconstruction, and have significant advantages in construction efficiency, cost control, low-carbon environmental protection, and functional adaptation. At the same time, the study also finds that the current rural promotion of modular buildings still faces problems such as insufficient cultural adaptation and lack of operation and maintenance system, which need to be improved in terms of localized design, cost and operation and maintenance optimization, and improvement of synergy mechanism. This study fills the gap in the systematic empirical research of modular architecture in rural areas and can provide practical reference for its large-scale promotion in rural areas.

In terms of future research, the research scope can be further expanded to explore the adaptive performance of modular buildings under different ethnic cultural backgrounds and climatic and geographical conditions. Long-term follow-up research can be carried out to verify the long-term operation effect and structural durability of rural modular building projects. In addition, it is necessary to further deepen the research on the integrated application of emerging technologies such as artificial intelligence (AI) parametric design and digital twin technology in modular buildings, so as to continuously improve the technical system and practical implementation path of modular buildings in rural applications.

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