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International Journal of Earthquake Engineering
Anno XLIII - Num. 1 - 2026

# Research on the design method of rural lodging based on the integration of architecture and environment

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**SUMMARY:** *This paper explores strategies for creating rural homestay landscapes based on the characteristics of BIM technology, simulating the construction process of integrating homestay structures with the surrounding landscape environment. It offers new insights for the healthy and sustainable development of rural homestay landscapes. Subsequently, the design outcomes of rural homestays under architectural-environmental integration are analyzed from both landscape aesthetics and spatial adaptability perspectives. It then proposes a Cuckoo Search (CS) algorithm-optimized BP neural network model (CS-BP) for predicting rural homestay environmental suitability to analyze audience satisfaction. Results indicate that spatial adaptability of rural homestays increases over time, particularly with highly correlated ecological landscape factors. Therefore, when designing rural homestays under conditions of building-environment integration, significant attention should be paid to developing local ecological landscapes. The minimal discrepancy between the model-predicted user satisfaction and actual values demonstrates the applicability of this model in rural homestay design.*

***KEYWORDS:*** *Cuckoo Search Algorithm; BP Neural Network; CS-BP Algorithm; Rural Homestay Design; BIM Technology*

## 1 Introduction

Against the backdrop of a rural leisure boom and the comprehensive advancement of rural revitalization, the rapid development of rural tourism has become a key focus for many county and township governments. Rural tourism has emerged as a new form of travel, breathing new life into the homestay industry [1, 2]. Globally, support for the homestay sector has shifted from vigorous promotion to a focus on quality enhancement, with its construction and operation moving toward standardization and premiumization [3, 4]. Connecting with nature and seeking nostalgia have become fashionable trends. While the primary function of rural homestays is accommodation, modern demands extend beyond material needs to include spiritual fulfillment. The yearning for rural landscapes reflects contemporary healthy green ecological values, while creating cultural landscapes preserves the authenticity of the site, enhances occupants' connection to the place, and meets the demands of modern rural homestay design [5-7]. As a type of rural architecture, rural homestays are not only a vital component for boosting rural income but also a window for showcasing and promoting rural characteristics, making their design methodology highly significant [8, 9].

After 2020, homestay development entered a bottleneck period. Compounded by the impact

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https://doi.org/10.65102/is2026141 Published: 30 April, 2026

of the COVID-19 pandemic, operations faced difficulties, and the number of homestays declined [10]. Over the past three years, with the recovery of the national tourism market, the homestay industry has shown a trend of “steady recovery,” while existing design issues have become increasingly apparent. First, developers, driven by self-interest, engage in large-scale demolition and construction, neglecting the protection of the site's ecological environment during the construction of homestays. Homestay providers, in the pursuit of maximizing their economic interests, often resort to ready-made design schemes, resulting in the increasing standardization of rural homestays that do not effectively reflect their unique features [11-14]. Secondly, the construction process of rural homestays shows excessive manipulation and urbanization trends. In particular, designers overemphasize the appearance of modernity, and often tear down the buildings and reconstruct them without exploring the essence of rural folk culture and customs. As a result, the rural cultural heritage is neglected in the designing process [15-18]. Thirdly, due to the absence of scientific planning, ground hardening, destruction of the native mountain waters and forests, and creation of artificial sceneries, rural homestays are often dull and hollow, easily causing visitors' aesthetic fatigue [19-21. The root cause of these problems lies in the deficiency in design consciousness and methods in rural homestay construction amid the rapid development of agriculture and rural modernization.

The theory of architectural environment integration has a rich tradition in history. From ancient times to modern times, from Eastern countries to Western countries, it has always focused on the harmony between human beings and nature, as well as architecture and nature [22]. With increasing environmental degradation due to human activities, sustainable design theories require the integration of architectural design into ecosystem design [23]. In a rural setting, the integration of spatial environment around us and the restoration of ecological landscapes could help restore neglected villages. For example, building houses that surround mountains and water and integrating the landscape around us, including mountains, forests, fields, and earthen architecture, represents the idea of architectural environment integration [24-26].

According to Reference [27], homestay design must comply with local tradition, respect the environment, and consider the architectural style of the region to ensure the highest level of environmental harmony, thus developing scientifically reasonable solutions for homestay design according to the local circumstances. Reference [28] introduce the development of art-themed homestays on Weizhou Island in China. In Ref. [28], sustainable development models for Weizhou Island homestays are proposed, noting that ecological and cultural preservation and community involvement are essential prerequisites for their sustainable development. Reference [29] mentions that integrating artistic and ecological elements into eco-friendly homestay facilities is one of the most important design methods for improving accommodation and promoting better experiences. In other words, such a method will maximize homestay design efficiency and preserve the natural landscape and culture of the island. Reference [30] suggests design principles for building homestays in Subensari Village, Malan City, stating that “the orderly development of architecture and the environment, with rational design playing an important role in the construction of homestays,” is required, as the natural landscape in the area is a critical component of developing ecotourism. Reference [31] introduces an integrated "Yangjia Le Homestay + X" development model based on the characteristics of homestays within rural revitalization and the current state of Yangjia Le homestays. Literature [32] utilizes local materials such as bamboo that is readily available in the construction of the homestays in Ged Pangrango Village, Sukabumi. In this way, the homestay is unique and contributes to community development. Literature [33] discusses various designs that can be used in designing homestays in order to incorporate culture into them: design which involves integration of spatial design and culture; eco-design in line with natural ecosystems; and material application design involving harmony of human habitation and environment. These designs represent the principles of harmony between architecture and its environment. Literature [34] advises that in the design of homestays, taking into consideration architectural environmental psychology, factors other than materials and buildings themselves should be taken into account. Specifically, architectural environmental psychology itself needs to be considered in spatial design. Moreover, the environment of the homestays should be adjusted according to the relationship between human culture and environment.

In this paper, the technical method and simulation techniques involved in the use of BIM technology in rural homestay landscapes through multi-party collaboration based on BIM capabilities are elaborated. The use of miniature models to simulate construction procedures is suggested to lay the groundwork for constructing multi-modal, multi-form, and multi-material homestay landscape projects. Thereafter, an integrated design procedure of rural homestay architecture and environment using BIM technology is introduced to provide guidance for innovative design values in rural homestays. Then, the attraction of rural homestay design, the aesthetic characteristics of their landscape design, and the spatial adaptability of rural homestay design are discussed, analyzing the design effects of rural homestays under the combination of architecture and environment. Finally, a CS-BP-based user satisfaction prediction model of rural homestay design is proposed for predicting the user experience satisfaction in the rural homestay design in five selected villages.

# 2 Rural Homestay Design Based on the Integration of Architecture and Environment

## 2.1 Application of BIM Technology in Homestay Landscapes

### 2.1.1 Miniature Model Simulation Design

The miniature model scene involves the construction of a miniature replica of an actual or already described real-life scenario, providing unique visual experiences to visitors. In this paper, the application and effectiveness of BIM models in homestay landscape projects have been investigated. Utilizing BIM technology to construct miniature homestay landscape models serves as the entry point for researching this project's viability. It involves coordinating the planning of prefabricated homestay structures with miniature landscape concepts to objectively showcase the spatial layout of the overall rural homestay plan. The design and construction of miniature homestay landscape models embody the forward-thinking approach of rural homestay projects within simulated experiments. The strategic model integrating BIM technology and homestay landscapes is illustrated in Figure 1.

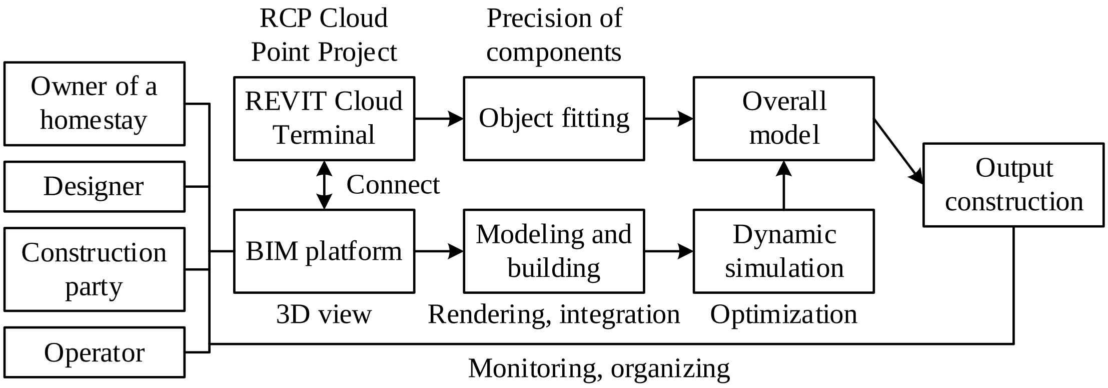



*Figure 1: BIM technology and the strategic mode of homestay landscape*

### 2.1.2 Construction Simulation Using Miniature Models

Exploring the Interconnectivity Features of BIM Technology, the utilization of BIM technology on cloud platforms has become a vital channel for professionals across disciplines to perform data conversion and scene modeling. Within the rural homestay landscape design framework, the industry ecosystem formed by clients, contractors, construction teams, and operational teams can be applied to miniature simulation construction through a series of processes. Therefore, it is essential to conduct multi-party inspections to effectively address issues such as anticipated building material assembly, workflow integration, and design layout during on-site construction of homestay landscapes. The technical approach for miniature simulation construction is illustrated in Figure 2.

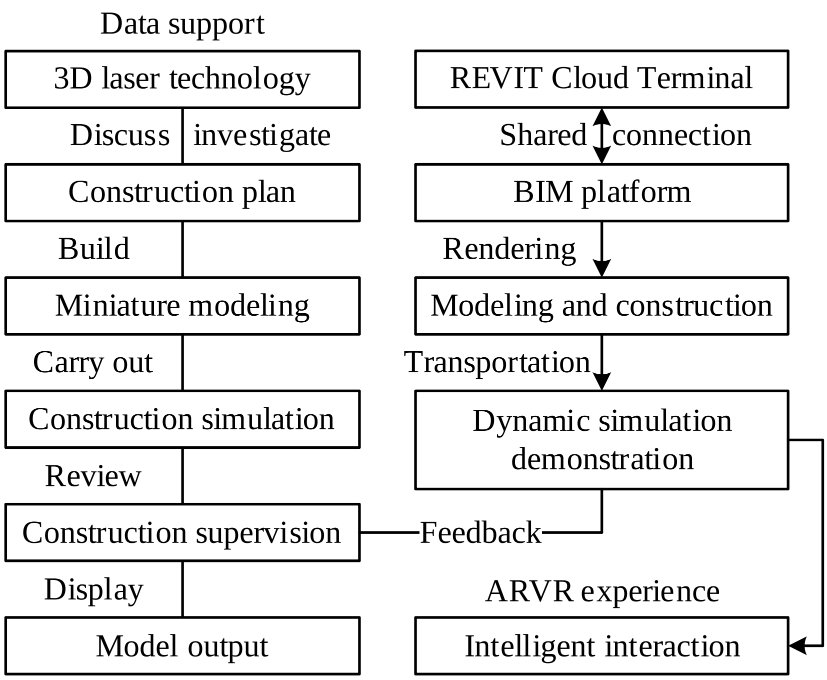



*Figure 2: Micro-scale simulation construction technology route*

### 2.1.3 BIM-Based Landscape Management for Rural Homestays

To implement BIM technology for managing homestay landscape construction, the following points must be achieved:

(1) Reduce Waste, Promote Green Construction

Applying BIM technology to homestay building renovations enhances efficiency, lowers renovation costs, and fosters healthy industry development.

(2) Diverse Shaping, Ecological Expression

Identify ecological models for different homestay types and scales, achieving ecological digital construction across various homestay layouts, levels, materials, and configurations.

(3) Emphasize Regionality, Highlight Distinctiveness

While conducting homestay landscape design, it is necessary to conduct an in-depth analysis of the cultural identity and local characteristics of the host city, together with the clear identification of the landscape design system to make sure that there is effective synergy between both the cultural identity and landscape components.

(4) Exploit resources to magnify the impact

Taking advantage of natural resources in countryside tourism and luring leisure visitors to come through luxury villas will be the best way of increasing countryside revenues and improving tourism impacts.

(5) Integrating Form and Meaning for Synergistic Development

The harmonious relationship between form and meaning in the homestay can indicate that it meets all natural requirements. Such an example can represent the countryside ecological environment and create a green living environment. The symbiosis of form and meaning can represent the harmonious combination of the countryside tourism environment.

## 2.2 Integration of Rural Homestay Architecture and Environment Based on BIM Technology

### 2.2.1 Entrance Design for Homestays

It is critical that the designer comprehensively understands the size and ratio of the entrance space. The entrance needs to be large enough to provide unity with the entire guest house. In addition, the uniqueness of the space will be highlighted, giving visitors an artistic experience. Moreover, attention needs to be paid to the indoor-outdoor relationship. Extension design style will be used to attract visitors from outside and make their senses enjoyable, all the while keeping the cultural ambience of the space. Therefore, through the reasonable design of entrance spaces, an interesting atmosphere will be formed.

### 2.2.2 Design of Homestay Courtyards

For the courtyard landscape design of homestays, the integration of environmental factors and resources in coordination with the philosophy of the homestay is required to form a stylistic courtyard landscape. Based on the philosophy of the homestay, the courtyard can be rationally designed, optimized, and adjusted in terms of landscape. It is critical not only to meet the requirements of guests but also to avoid ecological imbalance.

### 2.2.3 Design of Homestay Guest Rooms

In designing homestay guest rooms, apart from basic considerations of floor planning, lighting, and atmosphere, special attention needs to be paid to improving the aesthetic sense of the guest room. This improves the scenic effect, thereby helping guests relax thoroughly. On the other hand, keeping the room clean is imperative so as to maintain the cleanliness and hygiene. In homestay, the guest is looking forward to a calm environment. The room design thus also needs to protect the surroundings of the room, providing guests a peaceful sleeping space.

# 3 Analysis of Design Effects for Rural Homestays

## 3.1 Research Data Preparation

(1) Research Sample Site Photography and Selection

Photography Period: June 15 to June 30, 2025, when the weather was bright and sunny. The five villages chosen for the study were located in the XXX Region. They have been named Villages A, B, C, D, and E. Points photographed provided all-around views of the topographic features, vegetation, water features, agricultural landscape, buildings, small scale elements, and cultural tourism attractions of each village. Key sights in each village constituted the focus point of the photography work, reflecting the general features of the village. In total, fieldwork and photography provided 450 pictures, out of which 25 representative pictures were selected for evaluation purposes.

(2) Quantitative Evaluation of Rural Homestay Design Quality

This study engaged 100 professional evaluators to assess rural homestay designs. After scoring the scenic beauty of each photograph, evaluators were briefed on the scoring criteria, the meaning of each evaluation indicator, and the significance of ±2 points in scoring. They were then guided to rate the aesthetic quality of the rural homestays depicted in the photographs, with evaluation data recorded in real-time.

(3) Data Processing

A total of 100 valid evaluation data sets were collected. The data were imported into Excel for standardized processing using the following calculation formula:

$$Z_{ij} = \frac{R_{ij} - R_j}{S_j} \qquad Z_i = Z_{ij} / N_j \tag{1}$$

where $Z_{ij}$ is the standardized value of the $j$ th evaluator for the $i$ th landscape; $R_{ij}$ is the value of the $j$ th evaluator's rating for the $i$ th landscape; $R_j$ is the mean of the ratings of the $j$ th evaluator; $S_j$ is the standard deviation of the rating value of the $j$ th evaluator. $Z_i$ is the standardized score value of the $i$ th landscape: $N_j$ is the number of valid evaluators.

(4) Design Methodology

Through calculation, the respective scores for 25 rural homestay design photographs were obtained. The design approach was categorized into the following five methods to evaluate design effectiveness: Borrowing Scenery for Shelter (1), Concealed in Mountains and Forests (2), Utilizing Local Materials (3), Blending with Nature (4), and Building with the Landscape (5).

## 3.2 Rural B&B design favorability analysis

The results of the favorability of village B&B design are shown in Figure 3. The results show that under the methodology of this paper, the audience's favorability of the five villages in terms of borrowing scenery to build a house and being hidden in the mountains and forests are all positive, and the five design methods of “borrowing scenery to build a house, being hidden in the mountains and forests, taking materials from the local area, integrating into nature and building with the trend” have been combined in village A, which is a better overall performance. For villages B and E, the highest positive perceptions (1.1487 and 1.6457) were found in the B&Bs designed under the conditions of “taking materials in situ”, and the results for villages C and D showed that both villages had poorer application of the method of taking materials in situ, with negative perceptions of the B&B design, and the other four aspects of the design effect were better, but the designs of the two villages had their own focuses, with village B focusing on the use of materials in situ, and village D focusing on being hidden in the mountains and forests. However, the designs of the two villages have their own emphasis, with Village B focusing on locally sourced materials and Village D on being hidden in the mountains. On the whole, the overall favorability of the B&B designed in Village D is the highest, followed by Village A, Village E, and Village C. The overall effect of the B&B designed in Village B is the worst, and the mean values of the favorability of the B&B designs of the five villages are: 0.51312>0.51164>0.49786>0.41232>0.07276, respectively.

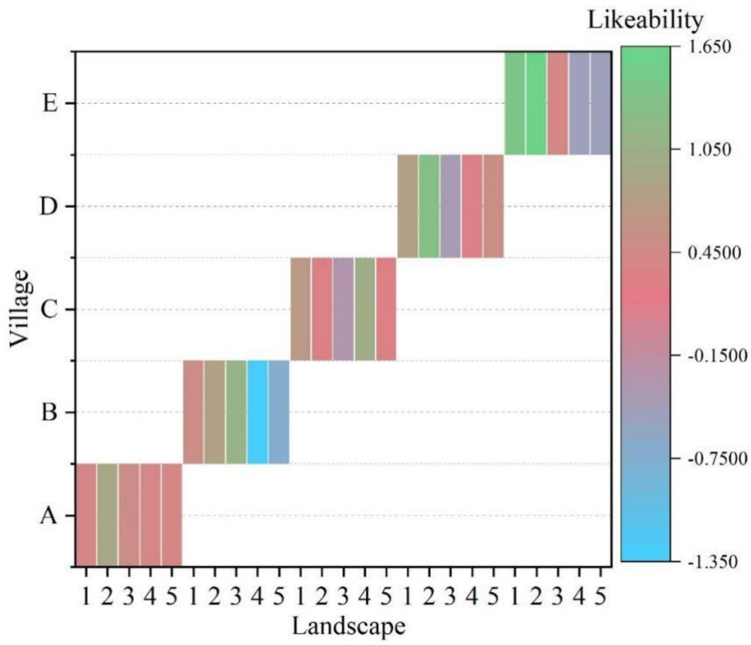



*Figure 3: Results of good feeling towards rural homestay design*

## 3.3 Analysis of the aesthetic quality of rural B&B landscape design

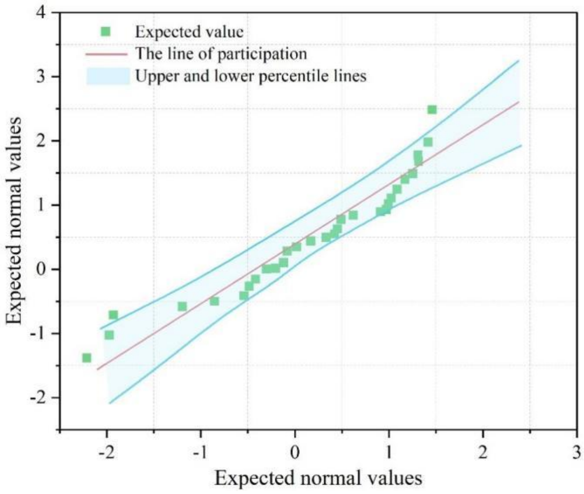
### 3.3.1 Normality test

(1) Normality test

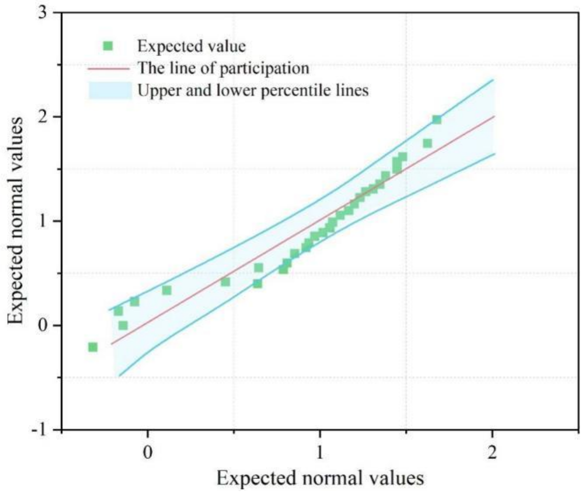
The data were tested for normality using SPSS software, and it was found that all landscape evaluation factors and beauty values were normally distributed (P>0.05).

(2) Normal Q-Q plot

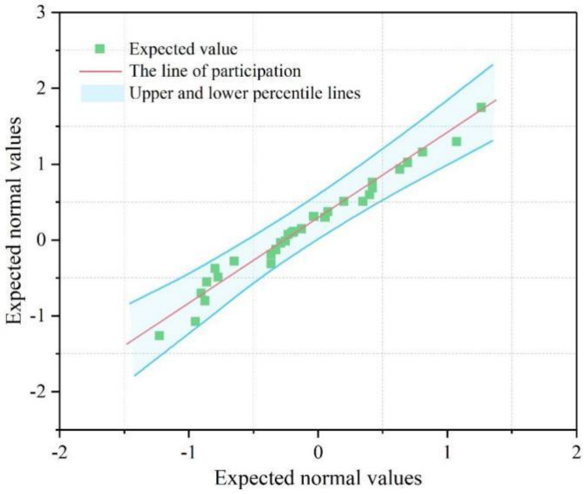
Q-Q diagram was used to observe whether the indicators conformed to normal distribution, and the results of normal distribution of each factor of the evaluation model are shown in Figure 4, where (a) ~ (d) represent the harmony between rural landscape and B&B, the coordination between plant landscape and B&B, the suitability of B&B design terrain and the coordination of colony architecture, respectively. The results show that all the design evaluation indexes and the beauty degree value of B&B design conform to normal distribution.



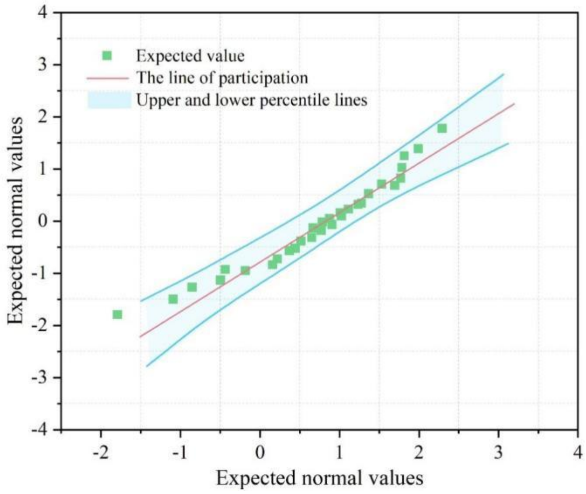

(a)Harmony between village landscape and homestay




(b)The harmony between plant landscape and homestay




(c)The suitability of homestay terrain design




(d)Harmony of settlement architecture

*Figure 4: Results of normal distribution of each factor in the evaluation model*

### 3.3.2 Correlation analysis of the degree of beauty in different evaluation groups

Exploring the correlation between professional aesthetic appeal scores and public aesthetic appeal scores in rural homestay design through correlation analysis. Pearson correlation coefficients are presented in Table 1, where ** denotes $p<0.01$. Detailed analysis reveals: the correlation coefficient between the aesthetic appeal scores of rural homestay designs by the professional group and the public group is 0.7261, exhibiting significance at the 0.01 level. This indicates a significant positive correlation between the aesthetic appeal scores of the professional group and the public group.

*Table 1: Pearson correlation coefficient*

| Scoring team | Average value | Standard error | Professional beauty index | Public beauty index |
|---|---|---|---|---|
| Professional beauty index | 0.68815 | 0.5214 | 1 | |
| Public Scenery Score | 0.74393 | 0.7345 | 0.7261** | 1 |

The aesthetic evaluations of rural homestay designs by different groups are shown in Figure 5. Both the professional and general groups demonstrated relatively uniform trends in evaluating the scenic beauty of the rural homestays designed using the concept of architectural-environmental harmony among the 25 series of photographs. It is clear that the scenic beauty of the rural homestays designed in this study is highly adaptable.

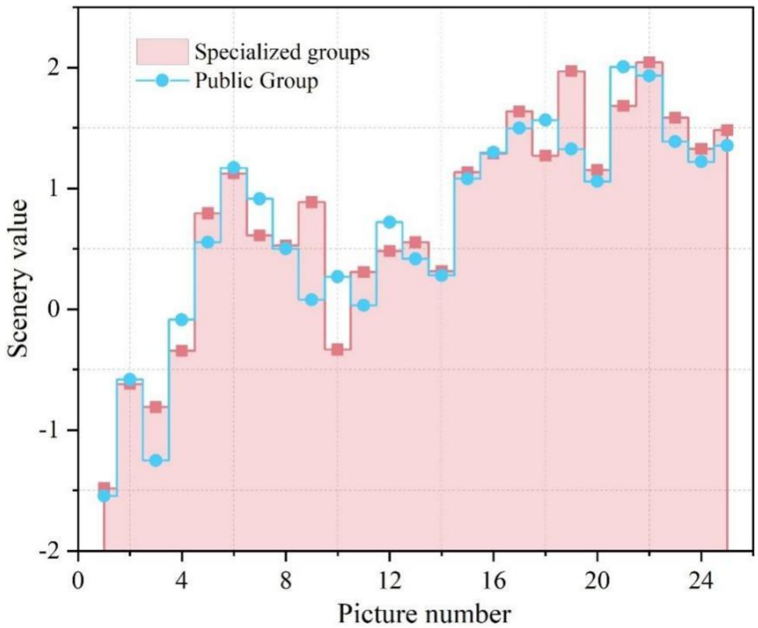



*Figure 5: Effect evaluation of rural homestay design*

### 3.3.3 Correlation Analysis Between Scenic Beauty and Landscape Evaluation Indicators

By conducting the correlation test, the connection between the scenic beauty score and four landscape indices was explored, including “rural landscape and homestays harmonious (A1), plant landscape and homestays harmonious (A2), homestay site suitable (A3), and homestay architecture coordination (A4).” The Pearson correlation coefficient was applied to determine the strength of the correlation. The correlation analysis between scenic beauty and each landscape feature is shown in Figure 6. Analysis reveals that scenic beauty exhibits significant positive correlations ($P < 0.05$) with all four landscape characteristics. The strongest correlations are observed between the harmony of settlement architecture and the suitability of homestay design terrain (correlation coefficient: 0.9871), followed by the harmony of settlement architecture and the harmony between rural landscapes and homestays (correlation coefficient: 0.9527). In comparison, the correlations between plant landscape and the harmony between the homestay and the surrounding landscape, as well as between plant landscape and the suitability of the terrain for homestay design, were slightly lower. However, their correlation coefficients still exceeded 0.85, clearly indicating a significant positive relationship between scenic beauty and the landscape evaluation indicators.

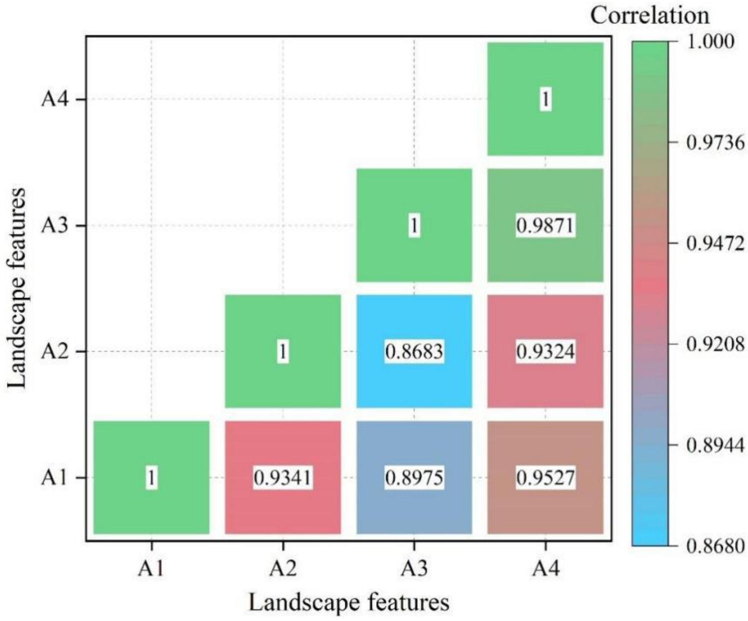



*Figure 6: Correlation analysis between scenic beauty and landscape features*

### 3.3.4 Establishing a Landscape Quality Evaluation Model

Linear regression analysis was conducted with scenic beauty as the dependent variable and four landscape feature factors as independent variables: "harmony between rural landscapes and homestays (A1), coordination between plant landscapes and homestays (A2), suitability of homestay design topography (A3), and coordination of settlement architecture (A4)". The results of the linear regression analysis are shown in Table 2, where * indicates $p < 0.05$ and ** indicates $p < 0.01$. The results indicate that the model's $R^2$ value is 0.9824, demonstrating that the four landscape evaluation factors—rural landscape harmony with homestays, plant landscape coordination with homestays, terrain suitability for homestay design, and settlement architecture coordination—can explain 98.24% of the variation in scenic beauty scores for rural homestay design.

*Table 2: Linear regression analysis results*

| | Non-standardized coefficient | | Standardization coefficient | *t* | *P* | Collinearity diagnostics | |
|---|---|---|---|---|---|---|---|
| | B | Standard error | Beta | | | VIF | Tolerance |
| Constant | 0.4143 | 0.2322 | - | 1.7679 | 0.0052 | - | - |
| A1 | 0.1231 | 0.1305 | 0.0929 | 3.9493 | 0.0000** | 3.9176 | 0.2538 |
| A2 | 0.278 | 0.168 | 0.1911 | 3.6433 | 0.0000** | 5.5724 | 0.1805 |
| A3 | -0.0766 | 0.1035 | -0.0777 | -2.7362 | 0.0000** | 4.8667 | 0.2045 |
| A4 | 0.0034 | 0.2054 | 0.0044 | 3.4017 | 0.0000** | 19.4966 | 0.0516 |
| $R^2$ | 0.9824 | | | | | | |
| Adjust $R^2$ | 0.9659 | | | | | | |
| F | F=45.3827, P=0.0000 | | | | | | |
| D-W | 2.1025 | | | | | | |

## 3.4 Spatial Adaptability Analysis

### 3.4.1 Spatial Adaptive Changes

This study analyzes the spatial adaptive changes in five selected villages from 2019 to 2024. "Form Order (FO), Structural Stability (SS), Functional Diversity (FD), and Spatial Adaptability (SA)" are the measures used to determine the presence of spatial adaptive changes. Rural homestay spatial adaptation changes are demonstrated in Figure 7 below. Results indicate that the overall spatial adaptation performance across the five villages showed a continuous upward trend in Form Order (FO), Structural Stability (SS), Functional Diversity (FD), and Spatial Adaptation (SA) from 2019 to 2024. However, the trends for Form Order (FO) and Structural Stability (SS) were relatively flat during this period, while Functional Diversity (FD) and Spatial Adaptability (SA) exhibited significant fluctuations. This is because while the overall form of rural homestays remains largely unchanged after design completion, the growing demand for tourism has prompted local scenic areas to optimize the functionality and spatial utilization of homestays to retain visitors. This explains the findings of this study. Overall, rural homestay designs that integrate architecture with the environment generally exhibit enhanced spatial adaptability.

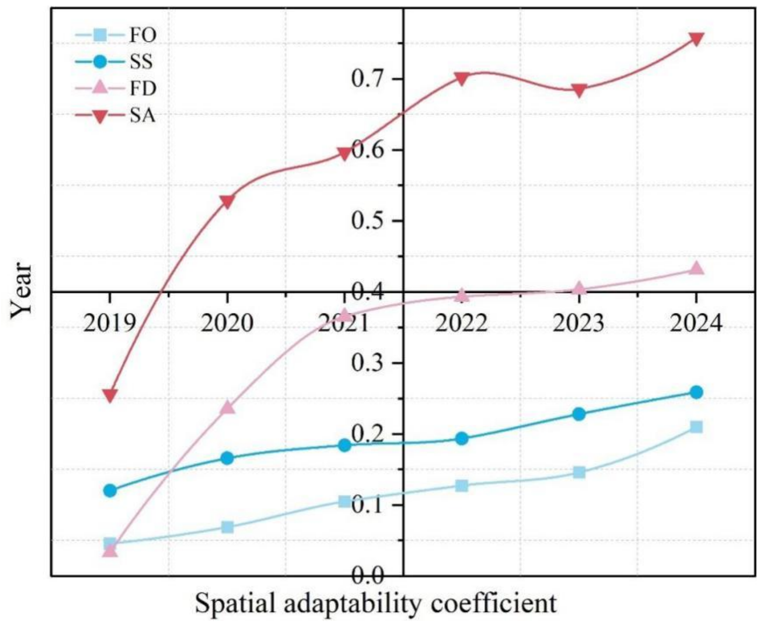



*Figure 7: Spatial adaptability change of rural homestay*

### 3.4.2 Correlation Analysis of Spatial Adaptability in Homestay Design

The correlation coefficients between spatial adaptability levels and factors such as morphological orderliness, structural stability, and functional diversity are presented in Table 3. It can be observed that under the influence of rural tourism, the correlation between rural homestay spatial adaptability and morphological orderliness and structural stability is moderate, with correlation coefficients of 1.5652 and 1.5711, respectively; whereas the correlation with functional diversity is relatively high (2.1475). Thus, under the influence of rural tourism, the spatial adaptability level of rural homestays is primarily affected by spatial functional diversity.

*Table 3: Results of correlations between factors*

| Influencing factor | Association values | Degree of relevance |
|---|---|---|
| Formal orderliness | 1.5652 | Medium degree of association |
| Structural stability | 1.5711 | Medium degree of association |
| Functional diversity | 2.1475 | High degree of association |

### 3.4.3 Analysis of Key Factors Influencing the Functional Diversity of Homestays

An analysis of the correlation between scenic appeal and spatial functional adaptability in rural homestays. The correlation between homestay functional diversity and spatial adaptability is shown in Table 4. It is evident that under the influence of rural tourism, the qualitative enhancement of living functions, the efficiency improvement of production functions, and the landscape enhancement of ecological functions all exert significant impacts on the adaptability of homestay functions. At the factor level, five indicators—"traditional building renovation utilization rate, per capita GDP, ecological service value per unit area, degree of ecological space landscape enhancement, and ecological environment quality"—exert the greatest influence on spatial functional diversity; with correlation coefficients exceeding 2 points, indicating extremely high correlation. The remaining indicators exhibit high correlation, with values ranging from 1.7842 to 1.9612, suggesting these factors also significantly influence the functional diversity of rural homestays. Additionally, the three factors within the ecological function landscape layer exert a substantial influence on the functional design of rural homestays under conditions of building-environment integration. Therefore, when designing rural homestays under such conditions, high priority should be given to the development of local ecological landscapes.

*Table 4: Correlation between functional diversity and spatial adaptability*

<table>
<tr><th>The guidelines layer</th><th>Factor layer</th><th>Degree of relevance</th><th>Factor layer</th><th>Association values</th><th>Degree of relevance</th></tr>
<tr><td rowspan="12">Functional diversity</td><td rowspan="6">Quality of life</td><td rowspan="6">1.8476</td><td>Facility completeness</td><td>1.8369</td><td>Tall</td></tr>
<tr><td>Road accessibility</td><td>1.9612</td><td>Tall</td></tr>
<tr><td>Per capita public services</td><td>1.8597</td><td>Tall</td></tr>
<tr><td>Facilities area</td><td>1.7011</td><td>Tall</td></tr>
<tr><td>Utilization rate of traditional building renovation</td><td>2.5478</td><td>Polar altitude</td></tr>
<tr><td>Inheritance of folk culture</td><td>1.8444</td><td>Tall</td></tr>
<tr><td rowspan="3">High efficiency of production function</td><td rowspan="3">1.9304</td><td>Gross domestic product per capita</td><td>2.3954</td><td>Polar altitude</td></tr>
<tr><td>Tourism input-output ratio</td><td>1.9061</td><td>Tall</td></tr>
<tr><td>Homestay design richness</td><td>1.7842</td><td>Tall</td></tr>
<tr><td rowspan="3">Landscape of ecological function</td><td rowspan="3">2.1039</td><td>Homestay residence satisfaction</td><td>2.1323</td><td>Polar altitude</td></tr>
<tr><td>Degree of landscape ecology and space</td><td>2.4297</td><td>Polar altitude</td></tr>
<tr><td>Ecological environment quality</td><td>2.0253</td><td>Polar altitude</td></tr>
</table>

# 4 Predicting User Satisfaction in Rural Homestay Design

## 4.1 Basic Algorithms

### 4.1.1 Cuckoo Search Algorithm

The Cuckoo Search (CS) algorithm [35] is one of the high-performance swarm intelligence optimization algorithms. Its fundamental concept originates from the Lévy flight behavior of birds and the brood parasitism of cuckoos. Lévy walk represents a class of non-Gaussian stochastic processes. During Lévy walk motion, short-range small steps and long-range large steps alternate. This mechanism prevents the algorithm from getting stuck in local minima while enabling convergence to the global maximum.

Within the entire search space of the CS algorithm, the Lévy distribution determines the distance of each cuckoo's flight. During its implementation, only one parameter $p_a$ needs to be adjusted. Therefore, the CS algorithm is relatively simple and easy to implement, making the cuckoo's nest-finding and egg-laying behavior applicable to solving optimization problems.

The steps of the Cuckoo Search Algorithm are as follows:

(1) Each cuckoo in the population lays only one egg at a time. Only one egg can be randomly placed in each nest:

(2) Some nests contain high-quality eggs, and these nests are retained for the next generation.

(3) The population size remains constant. The probability of an egg being discovered is $p_a \in [0,1]$.

The cuckoo search algorithm specifies that the position update process for all cuckoo individuals follows a Markov chain, with position updates determined by the following equation:

$$x_i^{(t+1)} = x_i^{(t)} + \alpha \oplus L\hat{e}vy(\lambda) \tag{2}$$

In the equation, the step size $\alpha > 0$ : The position of the $i$ th bird's nest in the $t$ th generation is denoted by $x_i^{(t)}$. From the above equation, it can be seen that the next position of cuckoo $i$ is determined by its current position $x_i^{(t)}$ and the transition probability. The Lévy random search path is denoted by $L(\lambda)$, where the random step size follows a Lévy distribution. The random step size can be derived from the following equation:

$$L\hat{e}vy(\lambda) - u = t^{-\lambda}, (1 < \lambda \le 3) \tag{3}$$

### 4.1.2 Backpropagation Neural Networks

The BP neural network topology model is shown in Figure 8. $u$ represents the input to a neuron, and $v$ represents the activation output. A neuron in a layer is denoted by the superscript and subscript of $u$ and $v$, respectively. For example, the input to the $i$ th neuron in the hidden layer is represented as $u_i^l$. Let the training sample set be denoted as $X$. For a selected training sample, its actual output is represented by $y_k$, and its desired output is denoted as $d_k$. Furthermore, let $W_{mi}$ denote the weights between the input layer and the hidden layer of the neural network, and $W_{ij}$ denote the weights between the hidden layer and the output layer. Let the iteration count be $n$. Here, both the actual output and the weights are functions of $n$.

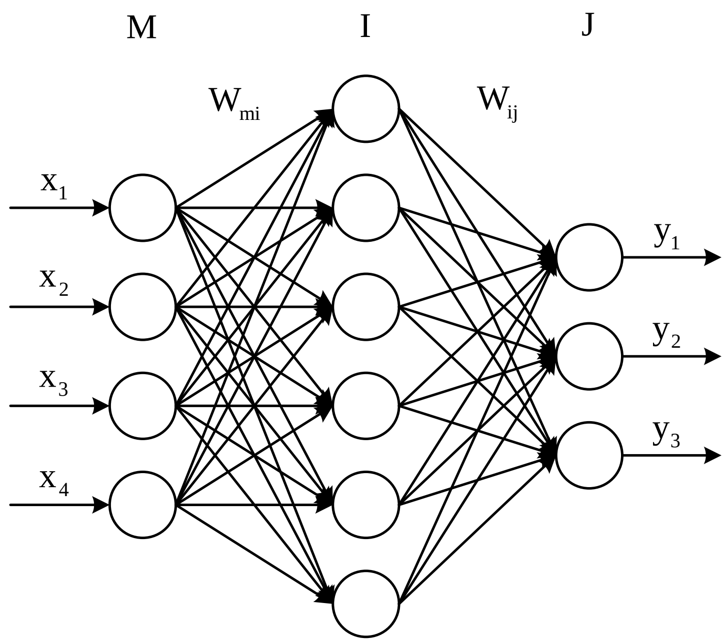



*Figure 8: Structure of BP Neural Network*

Regarding the aforementioned BP neural network training process, we analyze the iteration of a single BP neural network iteration. This learning process consists of forward signal propagation and backward error propagation for weight adjustment.

(1) Input the sample signal $X_k$ into the neural network. Through forward propagation of the signal, we obtain:

$$u_i^l = \sum_{m-1}^{M} w_{mi} x_{km} \tag{4}$$

$$v_i^l = f(u_i^l) = f\sum_{m-1}^{M} w_{mi} x_{km} \tag{5}$$

$$u_j^J = \sum_{i-1}^{I} w_{ij} v_i^I \tag{6}$$

$$v_j^J = \phi(u_j^J) = \phi(\sum_{i-1}^{l} w_{ij} v_i^l) \tag{7}$$

$$y_k = v_j^l = \phi(\sum_{i-1}^{l} w_{ij} v_i^l) \tag{8}$$

Accordingly, the error signal for the output layer neurons of the neural network can be calculated and expressed as:

$$e_k(n) = d_k(n) - y_k(n) \tag{9}$$

The total sum of error energy in the output layer of a neural network can be expressed as:

$$E(n) = \frac{1}{2}\sum_{j-1}^{j} e_k^2 \tag{10}$$

At this point, all learning errors of the neural network can be calculated through the output results of the BP neural network. Subsequently, the forward propagation of signals is immediately halted.

(2) The process then proceeds to the backpropagation of errors within the neural network. During this phase, the error signal propagates from the output layer through the hidden layer to the input layer. The connection weights of the neural network are sequentially modified from the output layer, through the hidden layer, to the input layer. This backpropagation of the error signal is described as follows:

This section focuses solely on the specific process of weight adjustment between the hidden layer and the output layer. In the BP neural network algorithm, the partial derivative of the error with respect to the weight is proportional to the weight adjustment amount, expressed as follows:

$$\Delta w_{ij}(n) \propto \frac{\partial E(n)}{\partial w_{ij}(n)} \tag{11}$$

And there is:

$$\frac{\partial E(n)}{\partial w_{ij}(n)} = \frac{\partial E(n)}{\partial u_j^J(n)} \times \frac{\partial u_j^J(n)}{\partial w_{ij}(n)} = \frac{\partial E(n)}{\partial e_k(n)} \times \frac{\partial e_k(n)}{\partial y_k(n)} \times \frac{\partial y_k(n)}{\partial u_j^J(n)} \times \frac{\partial u_j^J(n)}{\partial w_{ij}(n)} \tag{12}$$

According to the local gradient calculation formula:

$$\delta_j^J = -\frac{\partial E(n)}{\partial u_j^J(n)} = -\frac{\partial E(n)}{e_k(n)} \times \frac{\partial e_k(n)}{\partial y_k(n)} \times \frac{\partial y_k(n)}{\partial u_j^J(n)} = e_{k\{}(n)\psi'(u_j^J(n)) \tag{13}$$

It can be calculated that:

$$\frac{\partial E(n)}{\partial w_{ij}(n)} = -\delta_j^J \frac{\partial u_j^J}{\partial w_{ij}} \tag{14}$$

Because both the output layer and hidden layers of a neural network use the sigmoid function as their activation function, the following equation holds:

$$f(x) = \phi(x) = \psi(x) = \frac{1}{1+\exp(-x)} \tag{15}$$

$$e_k(n)\psi'(u_j^j(n)) = y_k(n)(1-y_k(n))(d_k(n)-y_k(n)) \tag{16}$$

It can then be calculated that:

$$\delta_j^j = \psi'(u_j^J(n)) = \frac{\partial v_j^J(n)}{\partial u_j^J(n)} = y_k(n)(1-y_k(n)) \tag{17}$$

Thus, the correction factor for $w_{ij}(n)$ can be calculated using the following equation:

$$\Delta w_{ij}(n) = -\eta \frac{\partial E(n)}{\partial w_{ij}(n)} = \eta\left(-\frac{\partial E(n)}{\partial u_j^J}\right)\frac{\partial u_j^J}{\partial w_{ij}} = \eta \delta_j^J(n) v_i^J(n) \tag{18}$$

where $\eta$ represents the learning step size, the weight adjustment after the next iteration is:

$$w_{ij}(n+1) = w_{ij}(n) + \Delta w_{ij}(n) \tag{19}$$

The above details the entire process of weight adjustment between the hidden layer and the output layer. The weight adjustment process between the hidden layer and the input layer follows the same procedure.

## 4.2 CS-BP-Based Prediction of User Satisfaction in Rural Homestay Design

The construction process of the Cuckoo Search (CS)-based BP neural network parameter optimization algorithm for predicting rural homestay environmental suitability (CS-BP) [36] is as follows:

Step 1: Collect historical time series data on rural homestay environmental suitability. Determine $\tau$ and $m$ using the mutual information method and association dimension method. Then reconstruct the rural homestay environmental suitability time series based on $\tau$ and $m$ to generate BP neural network training samples.

Step 2: Randomly generate $n$ nest positions $p_i^{(0)} = [x_1^{(0)}, x_2^{(0)}, \cdots, x_n^{(0)}]^T$, where each nest position corresponds to a set of initial connection weights for a BP neural network. The BP neural network trains on the training set using these initial connection weights, calculates the prediction accuracy for each set of nest positions, and identifies the current optimal nest $x_b^{(0)}$ based on this accuracy.

Step 3: Retain the optimal nest position $x_b^{(0)}$ from the previous generation. Update the other nests to obtain a new set of nest positions. Test these new positions and compare them with the previous generation's nest positions $p_{t-1} = [x_1^{(t-1)}, x_2^{(t-1)}, ..., x_n^{(t-1)}]^T$ to replace poorer nest positions with better ones, yielding an improved set of nest positions $k_t = [x_1^{(t)}, x_2^{(t)}, ..., x_n^{(t)}]^T$.

Step 4: Compare the random number $r$ with $P_a$. Retain nests in $k_i$ with lower discovery probabilities while randomly altering other nests to obtain a new set of nest positions. Test these new positions and compare each with corresponding positions in $k_t$ to replace inferior ones with superior ones, yielding an optimized set of nest positions: $p_t = [x_1^{(t)}, x_2^{(t)}, \cdots, x_n^{(t)}]^T$.

Step 5: Apply Gaussian perturbation to $p_t = [x_1^{(t)}, x_2^{(t)}, \cdots, x_n^{(t)}]^T$ to obtain a new set of nest positions $p_t^{'} = [x_1^{(t)^{'}}, x_2^{(t)^{'}}, \cdots, x_n^{(t)^{'}}]^T$. Test these positions and replace the poorer ones with the better ones to obtain an improved set of nest positions: $p_t^{''} = [x_1^{(t)^{''}}, x_2^{(t)^{''}}, \cdots, x_n^{(t)^{''}}]^T$ is obtained. For convenience in the next iteration, $p_t^{''}$ is denoted as $p_t$.

Step 6: Identify the optimal nest location $x_b^{(t)}$ from Step 5 and evaluate whether its test value meets the accuracy requirements for predicting rural homestay environmental suitability.

If satisfied, terminate the search and output the optimal nest $x_b^{(t)}$. Otherwise, return to Step 3 to continue searching.

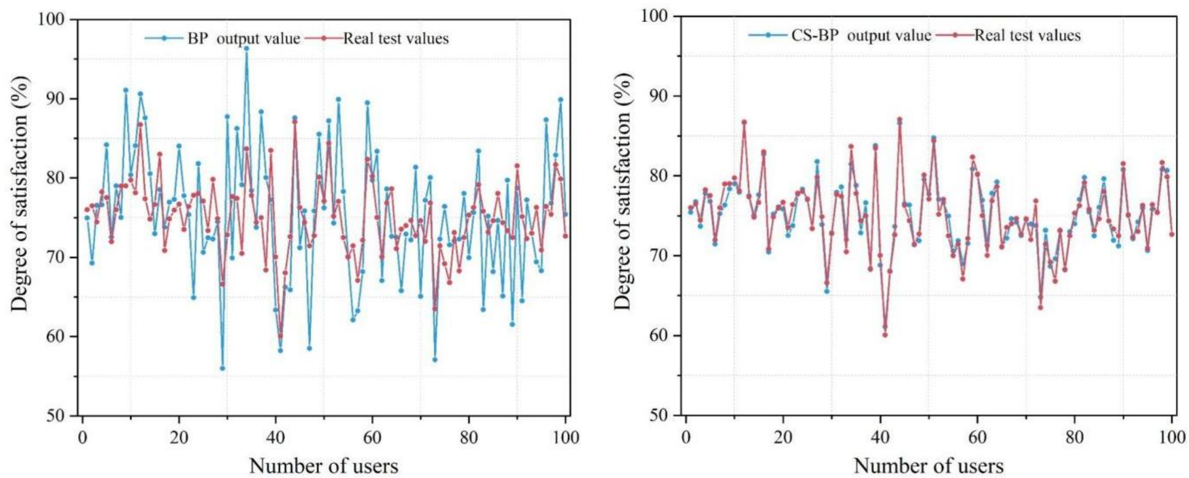
Step 7: Use the parameters corresponding to the optimal bird nest location $x_b^{(t)}$ as the initial connection weights and thresholds for the BP neural network. Retrain the model using the training set to establish the rural homestay environmental suitability prediction model. Apply this model to test the validation set.

## 4.3 Analysis of Satisfaction Prediction Performance

To evaluate whether the CS-BP model established in this study outperforms traditional models in rural homestay design, comparative experiments were conducted using both BP neural networks and the proposed algorithm.

This study involved 100 users evaluating their satisfaction with the residential experience of rural homestays featuring architecture-environment integration design. Ratings were assigned across five satisfaction levels: "Very Satisfied (80-100 points), Satisfied (70-80 points), Average (60-70 points), Somewhat Dissatisfied (50-60 points), Poor (<50 points)." With a maximum satisfaction score of 100 points, the actual values obtained were compared and analyzed against the predicted values from both models.

The experimental results of the two algorithms are shown in Figure 9, where (a) and (b) represent the prediction results of the BP algorithm and the proposed algorithm, respectively. The test outcomes on the BP model reveal significant differences between the predicted scores and the real figures, showing the largest difference at 19.89% which means a lack of accuracy in prediction. The CS-BP model in the present paper has shown nearly identical figures with minimum error margins and hence exhibits high predictability. Detailed analysis proves the success of the proposed method in achieving greater accuracy in predicting user satisfaction.




(a) The prediction result of BP algorithm (b) The prediction result of CS-BP algorithm

*Figure 9: Experimental results of the two algorithms*

The comparison results of the fitting performance between the two algorithms are shown in Table 5. The results indicate that the BP neural network model exhibited the highest average relative error and average absolute error during testing, along with the lowest coefficient of determination. Its performance was significantly inferior to that of the SC-BP model. Furthermore, the fitted value of the proposed model reached 0.9934, whereas the BP algorithm yielded only 0.7236. In comparison, the proposed algorithm demonstrated superior fitting performance. Experimental results demonstrate that the proposed algorithm enables more accurate prediction of user satisfaction with rural homestay designs. This holds significant practical implications for designing rural homestays under conditions of architectural and environmental integration.

*Table 5: Comparison of fitting effects of the two algorithms*

| Algorithm | MAE | MPAE | $R^2$ |
|---|---|---|---|
| BP | 1.5741 | 0.2566 | 0.7236 |
| CS-BP | 0.4381 | 0.0107 | 0.9934 |

# 5 Conclusion

This paper introduces BIM-based design methodologies for integrating rural homestay architecture with its environment, starting from the application of BIM technology in homestay landscapes. It starts off by evaluating the design of the homestay with three aspects, including perceived attractiveness of the same. It finally comes up with a model using the cuckoo search algorithm to optimize the BP neural network parameters for prediction of satisfaction with the homestays within the rural environments. From the findings, we learn that:

(1) The proposed model shows high predictability when applied to rural homestay attractiveness.

(2) Over 98% of variations in scenic appeal are attributed to four landscape evaluation factors: “harmony between rural landscapes and lodgings,” “coordination between plant landscapes and lodgings,” “terrain suitability in lodging design,” and “coordination with settlement architecture.” Thus, these aspects warrant high priority in rural homestay design.

(3) Rural homestay designs across different regions should adopt a site-specific approach, emphasizing local characteristics—particularly the development of ecological and environmental landscapes.

(4) The CS-BP model used in this study exhibits minimal prediction error between its user satisfaction estimates and actual values, making it suitable for evaluating satisfaction with rural homestay design outcomes.

# Funding

This research was supported by the Anhui Provincial Department of Education Philosophy and Social Sciences Key Research Project "Research on the Development Path of the "Famous Residence +" Model under the Rural Revitalization Strategy" (Item number: 2023AH052812).

Anhui Provincial Department of Education Teaching Research Key Project (Project Number: 2022jyxm636)

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