RESEARCH ARTICLE

Application of fuzzy comprehensive evaluation in green design of ecological garden landscape

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With the acceleration of urbanization, the green design of ecological garden landscape is becoming more important. However, traditional evaluation methods are difficult to meet the needs of accurate and scientific evaluation. This research deeply studied the application of fuzzy comprehensive evaluation in the green design of ecological garden landscape by taking 50 ecological garden landscape design projects in Nanjing, Jiangsu, China as the study subjects. The fuzzy comprehensive evaluation method was compared with the traditional evaluation method. By constructing a fuzzy matrix, determining the membership function, and using the analytic hierarchy process to determine the weight, the evaluation indicators were fully quantified. The results showed that, in terms of environmental factor evaluation, landscape aesthetics evaluation, and ecological function evaluation, the average scores of traditional evaluations were 3.2, 3.3, and 3.0, while the average scores of the fuzzy comprehensive evaluation were 4.0, 4.1, and 3.8, respectively. The fuzzy comprehensive evaluation method demonstrated significant advantages. The study showed that fuzzy comprehensive evaluation could effectively solve the fuzziness and uncertainty of evaluation indicators, provide a scientific and accurate evaluation basis for the green design of ecological garden landscape, and promote the development of this field in a more scientific and sustainable direction.

Keywords: fuzzy comprehensive evaluation; ecological garden landscape; green design; quantitative analysis; evaluation index system.

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Introduction

Green design in ecological landscape architecture is receiving increasing attention as an important component of sustainable urban development. With the acceleration of urbanization, urban landscapes face growing environmental pressures, and the design and construction of ecological landscape architecture are considered an effective way to address these urban environmental challenges [1]. Through reasonable plant configuration, greening and beautification, and optimization of landscape facilities, ecological gardens can not only enhance urban greening, but also help regulate microclimate, improve air quality, and increase biodiversity [2].

Green design is based on ecological principles, integrating landscape aesthetics and functional needs to create spaces that conform to natural laws and human needs [3]. Its core lies in enhancing the stability and sustainability of ecosystems through the rational selection of plants and landscape layout, thereby maximizing ecological benefits. Studies have shown that urban green spaces can mitigate the heat island effect and regulate microclimates [4]. The focus of green design has gradually shifted from purely aesthetic orientation to multidimensional evaluation systems that include ecological functions, water resource management, and pollution control [5]. To address the complexity of design objectives, many studies have employed methods of environmental impact assessment, ecological principles, and integrated eco-social-economic approaches [6]. Despite some progress, current theoretical frameworks often struggle to integrate multiple objectives, particularly in balancing ecological, social, and economic benefits during the decision-making process [7]. Existing methods often emphasize a single objective but fail to adequately consider the interrelationships between multiple objectives [8]. Furthermore, traditional evaluation methods are easily influenced by subjective factors and lack the ability to handle uncertainties and ambiguities in multi-objective, multi-level design tasks. Fuzzy comprehensive evaluation combines fuzzy logic with comprehensive evaluation, integrating qualitative and quantitative indicators, quantifying fuzzy factors using membership functions, and determining indicator weights through the analytic hierarchy process (AHP) [9-12]. This method has been shown to comprehensively assess environmental, social, and economic dimensions [13], reduce subjectivity, and support more accurate decision-making. However, challenges remain in indicator selection, weight allocation, and large-scale data processing [14, 15]. Meanwhile, multi-objective optimization methods such as genetic algorithms (GA) and particle swarm optimization (PSO) have been applied to balance competing objectives and optimize plant species selection, spatial distribution and ecosystem stability [16-18], but objective integration and model constraint definition remain challenging [19].

This study aimed to optimize the green design of ecological landscapes by integrating environmental, social, and economic factors into a unified system model using fuzzy comprehensive evaluation. This was the first time that fuzzy comprehensive evaluation had been applied to the green design of ecological landscapes. By constructing a scientific, quantitative, and systematic evaluation framework, this study provided a basis for design optimization, improved the overall quality of ecological landscapes, and promoted the sustainable development of urban landscapes. It was of great significance to both theoretical development and practical application of this field.

Materials and methods

Basic principles of fuzzy comprehensive evaluation

In the green design of ecological garden landscapes, fuzzy comprehensive evaluation based on fuzzy mathematics provided an effective solution for complex and fuzzy multidimensional evaluation indicators. Its core was to construct a fuzzy matrix and combine it with membership functions to realize the quantitative evaluation and weight allocation of various evaluation indicators, thereby obtaining the comprehensive score of each design scheme. When facing multiple evaluation indicators for a given design solution $x_1, x_2, \dots, x_n$, the first task was to define a membership function $\mu_i(x_j)$ to represent the degree of membership of the j-th indicator x_j under the evaluation indicator x_i. The choice of membership function was closely related to the characteristics of the specific evaluation index. Common membership functions included triangular membership function, trapezoidal membership function, and Gaussian membership function. For the triangular membership function, a certain evaluation indicator x could be expressed as follows if its value range was $[a, b, c]$.

$$\mu(x) = \begin{cases} 0, & x \le a \\ \frac{x-a}{b-a}, & a < x \le b \\ \frac{c-x}{c-b}, & b < x \le c \\ 0, & x > c \end{cases} \quad (1)$$

This function form could intuitively reflect the changes in the degree of membership of the indicator within different value ranges, providing a basis for subsequent quantitative analysis.

Calculation method of fuzzy comprehensive evaluation

For a specific evaluation scheme A_k , its comprehensive evaluation result C_k could be calculated below.

$$C_k = \sum_{i=1}^{n} w_i \cdot \mu_i(x_j) \quad (2)$$

where w_i was the weight of the evaluation index i, which reflected the importance of each index in the design scheme. There were many ways to determine the weight. The most common ones were the AHP and entropy weight method. A judgment matrix needed to be built. By organizing experts to compare the relative importance of each index, a judgment matrix $A = (a_{ij})_{n\times n}$ could be obtained, where a_{ij} represented the importance of the index i. The maximum eigenvalue of the judgment matrix λ_{max} and its corresponding eigenvector W were then calculated as follows.

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(AW)_i}{W_i} \quad (3)$$

where $(AW)_i$ was the i-th element of the vector. After obtaining the maximum eigenvalue and eigenvector, a consistency test was required for the consistency index CI calculation.

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (4)$$

The random consistency index RI could be obtained by looking up the table of consistency ratio $CR = \frac{CI}{RI}$. At this point, the judgment matrix had satisfactory consistency, and the weight vector obtained at this time was $CR < 0.1$. W was valid and could be used for subsequent comprehensive evaluation calculations.

Practical application of fuzzy comprehensive evaluation in green design of ecological garden landscape

In the practical application of green design of ecological garden landscape, fuzzy comprehensive evaluation could flexibly deal with multi-level and multi-dimensional factors such as environmental factors, landscape aesthetics, and ecological functions. In terms of environmental factors, it covered soil quality, light conditions, water resource utilization, *etc*. Let the soil pH index be x_1, the fertility index be x_2 , and the permeability index be x_3 , the corresponding membership functions were $\mu_1(x_1)$, $\mu_2(x_2)$, $\mu_3(x_3)$, respectively. Assuming that the soil pH value obtained through laboratory testing was pH, the nitrogen content in the fertility index was N , the phosphorus content was P, the potassium content was K, and the porosity related parameter of permeability was θ, if a triangular membership function was constructed, for the soil pH, the range suitable for the growth of common local plants was set to $[a_1, b_1, c_1]$, then the specific formula was below.

$$\mu_1(x_1) = \begin{cases} 0, & pH \le a_1 \\ \frac{pH - a_1}{b_1 - a_1}, & a_1 < pH \le b_1 \\ \frac{c_1 - pH}{c_1 - b_1}, & b_1 < pH \le c_1 \\ 0, & pH > c_1 \end{cases} \quad (5)$$

For the fertility index, assuming that the appropriate ranges were determined based on research with the nitrogen content as $[a_2, b_2, c_2]$, phosphorus content as $[a_3, b_3, c_3]$, and potassium content as $[a_4, b_4, c_4]$, the formula was then as follows.

$$\mu_2(x_2) = \omega_N \begin{cases} 0, & N \le a_2 \\ \frac{N - a_2}{b_2 - a_2}, & a_2 < N \le b_2 \\ \frac{c_2 - N}{c_2 - b_2}, & b_2 < N \le c_2 \\ 0, & N > c_2 \end{cases} +$$

$$\omega_P \begin{cases} 0, & P \le a_3 \\ \frac{P-a_3}{b_3-a_3}, & a_3 < P \le b_3 \\ \frac{c_3-P}{c_3-b_3}, & b_3 < P \le c_3 \\ 0, & P > c_3 \end{cases} + \omega_K \begin{cases} 0, & K \le a_4 \\ \frac{K-a_4}{b_4-a_4}, & a_4 < K \le b_4 \\ \frac{c_4-K}{c_4-b_4}, & b_4 < K \le c_4 \\ 0, & K > c_4 \end{cases} \quad (6)$$

where ω_N , ω_P , ω_K were the weights of nitrogen, phosphorus, and potassium in the fertility index, and $\omega_N + \omega_P + \omega_K = 1$. For the air permeability index, if the appropriate range of porosity was $[a_5, b_5, c_5]$, then the calculation was as below.

$$\mu_3(x_3) = \begin{cases} 0, & \theta \le a_5 \\ \frac{\theta-a_5}{b_5-a_5}, & a_5 < \theta \le b_5 \\ \frac{c_5-\theta}{c_5-b_5}, & b_5 < \theta \le c_5 \\ 0, & \theta > c_5 \end{cases} \quad (7)$$

The comprehensive membership of soil quality μ_{soil} was then calculated as follows.

$$\mu_{soil} = w_1\mu_1(x_1) + w_2\mu_2(x_2) + w_3\mu_3(x_3) \quad (8)$$

where w_1, w_2, w_3 were the weights of soil pH, fertility, and permeability indicators, respectively. In terms of landscape aesthetics, it involved the coordination of plant matching and the rationality of spatial layout. Let the color matching index be y_1, the height staggered index be y_2, and the seasonal change index be y_3. Through expert scoring, the qualitative aesthetic feeling was converted into a quantitative score. Assuming that the set of expert scores was $S = \{s_1, s_2, \cdots, s_m\}$, the membership function of the color matching index was expressed as below.

$$\mu_{y_1}(s) = \frac{\sum_{i=1}^{m} s_i \delta_{i1}}{\sum_{i=1}^{m} \delta_{i1}} \quad (9)$$

where δ_{i1} was the judgment function. When the color matching index was evaluated, $\delta_{i1} = 1$, otherwise it was 0. Similarly, the membership functions of the high and low staggered index and the seasonal change index could be obtained as $\mu_{y_2}(s)$ and $\mu_{y_3}(s)$. The comprehensive membership of the coordination of plant matching $\mu_{coordination}$ was then calculated as follows.

$$\mu_{coordination} = v_1\mu_{y_1}(s) + v_2\mu_{y_2}(s) + v_3\mu_{y_3}(s) \quad (10)$$

where v_1 , v_2 , v_3 were the weights of color matching, high and low staggered, and seasonal change indicators, respectively. In terms of ecological functions, it included biodiversity protection and carbon sink capacity. When evaluating the ecological functions of plant combinations, the carbon fixation and oxygen release capacity index was z_1 , the water conservation capacity index was z_2, and the air purification capacity index was z_3. Assuming that the carbon fixation and oxygen release data per unit area of different plants were C_{fix}, and the actual planting area of the garden was A, the membership function of the carbon fixation and oxygen release capacity index was as follows.

$$\mu_{z_1}(C_{fix}) = \begin{cases} 0, & C_{fix} \le d_1 \\ \frac{C_{fix}-d_1}{e_1-d_1}, & d_1 < C_{fix} \le e_1 \\ \frac{f_1-C_{fix}}{f_1-e_1}, & e_1 < C_{fix} \le f_1 \\ 0, & C_{fix} > f_1 \end{cases} \quad (11)$$

where $[d_1, e_1, f_1]$ was the suitable range of carbon fixation and oxygen release capacity determined according to the research. Similarly, for the water conservation capacity index, assuming that the relevant parameters were $W_{retention}$ and the suitable range was $[d_2, e_2, f_2]$, the membership function was as below.

$$\mu_{z_2}(W_{retention}) = \begin{cases} 0, & W_{retention} \le d_2 \\ \frac{W_{retention}-d_2}{e_2-d_2}, & d_2 < W_{retention} \le e_2 \\ \frac{f_2-W_{retention}}{f_2-e_2}, & e_2 < W_{retention} \le f_2 \\ 0, & W_{retention} > f_2 \end{cases} \quad (12)$$

For the air purification capacity index, assuming that the relevant parameter was $P_{purification}$ and the suitable range was $[d_3, e_3, f_3]$, the membership function was expressed below.

$$\mu_{z_3}(P_{purification}) = \begin{cases} 0, & P_{purification} \le d_3 \\ \frac{P_{purification}-d_3}{e_3-d_3}, & d_3 < P_{purification} \le e_3 \\ \frac{f_3-P_{purification}}{f_3-e_3}, & e_3 < P_{purification} \le f_3 \\ 0, & P_{purification} > f_3 \end{cases} \tag{13}$$

The comprehensive membership of ecological functions of plant combinations $\mu_{ecological}$ was then as follows.

$$\mu_{ecological} = u_1\mu_{z_1}(C_{fix}) + u_2\mu_{z_2}(W_{retention}) + u_3\mu_{z_3}(P_{purification}) \tag{14}$$

where u_1 , u_2 , u_3 were the weights of the indicators of carbon fixation and oxygen release capacity, water conservation capacity, and air purification capacity, respectively. When implementing fuzzy comprehensive evaluation, attention should also be paid to the accuracy and reliability of the data. For environmental monitoring data, scientific sampling methods and precise testing instruments should be used. For expert evaluation data, the professionalism of experts and the fairness of the evaluation process should be ensured. Meanwhile, with the development of ecological garden landscape design and the deepening of research, the evaluation index system and membership function were constantly updated and improved to adapt to new design concepts and practical needs. Through fuzzy comprehensive evaluation, multiple evaluation dimensions of each design scheme were combined to calculate the comprehensive score, and the design schemes were ranked according to these scores, providing important basic data for subsequent multi-objective optimization and the determination of the final design scheme. The method converted qualitative data into quantitative results, effectively solved the ambiguity and uncertainty of evaluation indicators in ecological garden landscape design, and made the evaluation of design schemes more scientific and accurate.

Experimental design

A total of 50 ecological garden landscape projects located in Nanjing, Jiangsu, China was involved in this research. Data from March to October 2024 was collected, which covered both the spring–summer and summer–autumn seasonal transitions to account for seasonal variation. A total of 150 sets of raw data were obtained including environmental factors of soil pH, nutrient content, permeability, light intensity, water resource utilization, landscape aesthetics of plant coordination, spatial layout, seasonal change, and ecological functions of biodiversity, carbon sink capacity, ecological stability. Environmental data were collected using INESA PHSJ-4F portable soil pH meter (INESA Scientific Instrument Co., Ltd., Shanghai, China), soil nutrient analysis kits provided by Nanjing Agricultural University (Nanjing, Jiangsu, China), and TZ-5 porosity tester (Top Instrument Co., Hangzhou, Zhejiang, China) [20]. Light intensity was measured using a CEM LX-1010B digital lux meter (CEM Instruments, Shenzhen, Guangdong, China) three times a day for five consecutive days and averaged for analysis. The design evaluation data was obtained through on-site observation, photographic documentation, and expert scoring following standardized guidelines. Data processing and fuzzy comprehensive evaluation modeling were conducted. The experimental procedures consisted of site survey and baseline environmental data collection, indicator system construction, membership function determination, weight assignment using the Analytic Hierarchy Process, and comprehensive scoring and comparative analysis between traditional and fuzzy comprehensive evaluation methods [21]. The traditional ecological garden landscape evaluation method was used as the control based on the "National Standard for Urban Green Space Evaluation" (GB/T 50341-2016) issued by the Ministry of Housing and Urban-Rural Development of the People's Republic of China (http://www.mohurd.gov.cn) and the "Landscape Quality Assessment Guidelines" developed by the Chinese Society of Landscape Architecture (Beijing, China). Evaluations were conducted by a panel of five certified senior landscape architects registered with the Jiangsu Provincial Department of Housing and Urban-Rural Development and primarily relied on expert visual inspection, qualitative scoring, and checklist-based assessments. The evaluation system constructed for this study comprised three primary dimensions with specific indicators, which covered environmental factors including soil pH, soil fertility (nitrogen, phosphorus, potassium content), soil permeability, light intensity, water resource utilization rate; landscape aesthetics including plant color coordination, height arrangement, seasonal variation, spatial layout rationality, overall visual harmony; ecological functions including biodiversity index, carbon fixation and oxygen release capacity, water conservation capacity, air purification capacity, ecological stability index. These indicators were selected based on national landscape assessment guidelines, ecological design principles, and relevant literature to ensure scientific validity and practical applicability. All data analysis was performed using MATLAB R2023b (MathWorks, Natick, MA, USA) and ArcGIS Pro 3.2 (Esri, Redlands, CA, USA) for spatial visualization. The fuzzy comprehensive evaluation algorithm and AHP were implemented using MATLAB toolboxes with custom scripts developed by the research team. All indicator values were obtained through standardized field measurements, laboratory testing, and expert scoring protocols. Biodiversity indices were calculated based on species counts from field surveys. Carbon fixation and oxygen release capacity were estimated using established coefficients from the Chinese Forestry Science Database. Water conservation capacity was determined by measuring soil water-holding capacity, while air purification capacity was assessed using particulate matter (PM2.5) and sulfur dioxide (SO_2) removal rates based on literature-derived factors. Aesthetic indicators were scored by five independent experts using a 1–5 scale.

Statistical analysis

SPSS 27.0 (IBM, Armonk, NY, USA) was employed for statistical analysis of this study. Student t-tests were used for normally distributed variables, while Mann–Whitney U tests were used for non-normal variables. Normality was assessed using the Shapiro–Wilk test. *P* value less than 0.05 was considered as statistically significant difference.

Results and discussion

Evaluation of environmental factors

The results demonstrated that the scores of the fuzzy comprehensive evaluation method were generally higher than those of the traditional evaluation method (Figure 1). The differences in the scores of soil quality, light conditions, and water resource utilization were all positive, which was because the fuzzy comprehensive evaluation method could accurately quantify the actual status of each environmental factor by constructing a membership function, converting qualitative descriptions into quantitative analysis, and thus more accurately reflecting the pros and cons of environmental factors. In soil quality assessment, the fuzzy comprehensive evaluation comprehensively considered the interactive effects of multiple indicators including soil acidity, fertility, and permeability and achieved a comprehensive assessment of soil quality through reasonable weight allocation. However, traditional evaluation methods were highly subjective, and it was difficult to comprehensively and accurately consider these factors.

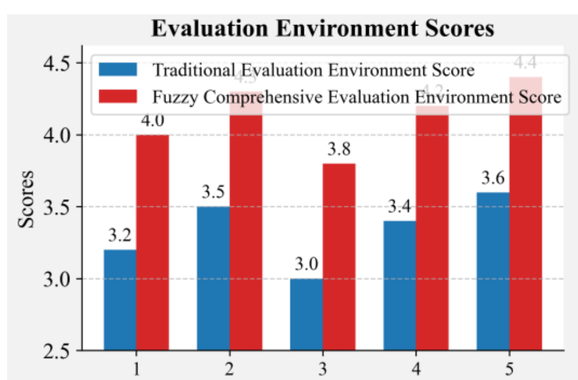

Figure 1. Comparison of environmental factor evaluation results using different evaluation methods.

Table 1. Comparison of ecological function evaluation results by different evaluation methods.

Project No.	1	2	3	4	5
Traditional evaluation of ecological function scores	3.0	3.2	2.8	3.3	3.4
Fuzzy comprehensive evaluation of ecological function scores	3.8	4.0	3.6	4.1	4.2
Difference in biodiversity conservation score	0.3	0.4	0.3	0.4	0.5
Carbon sink capacity score difference	0.3	0.3	0.2	0.3	0.4
Ecological stability score difference	0.3	0.4	0.3	0.4	0.4

Landscape aesthetics evaluation

The fuzzy comprehensive evaluation performed better in landscape aesthetics evaluation (Figure 2). The difference in the scores of plant coordination, spatial layout rationality, and overall aesthetics was positive. Fuzzy comprehensive evaluation considered factors including the color, height, and seasonal changes of plant by constructing a multi-dimensional evaluation index system and using a scientific weight determination method to make the evaluation results more objective and comprehensive. In contrast, traditional evaluation methods were greatly influenced by the personal aesthetics and experience of experts, making it difficult to achieve such a detailed and scientific evaluation.

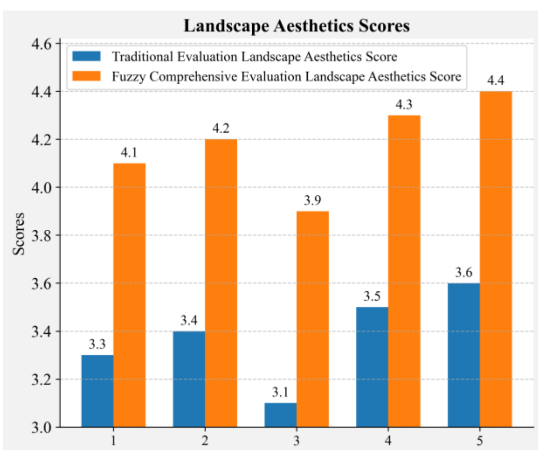

Figure 2. Comparison of landscape aesthetics evaluation results using different evaluation methods.

Ecological function evaluation

The fuzzy comprehensive evaluation method scored higher than the traditional evaluation method in terms of biodiversity protection, carbon sink capacity, and ecological stability (Table 1). Fuzzy comprehensive evaluation was based on specific quantitative indicators such as the carbon fixation and oxygen release capacity, water conservation capacity, and air purification capacity of plants. Through reasonable membership functions and weight distribution, it could achieve accurate evaluation of ecological functions. However, the traditional evaluation method was relatively general in its evaluation of ecological functions, lacking specific data support and scientific quantitative analysis.

Comparison of comprehensive scores of different evaluation methods

The comprehensive score of fuzzy comprehensive evaluation was significantly higher than that of traditional evaluation method, and there were also obvious differences in the proportion of environmental factors and landscape aesthetics scores (Table 2), which was because fuzzy comprehensive evaluation scientifically integrated the results of each evaluation dimension and fully considered the relationship and weight between various factors, while traditional evaluation method lacked systematicity and scientificity in comprehensive evaluation. The weight distribution of each indicator in the fuzzy comprehensive evaluation showed that, among the environmental factors, the weights of soil quality and water resource utilization were relatively high because they played more critical roles in the basic support of ecological garden landscape. Meanwhile, there were certain correlations between the indicators such as the high correlation between soil quality and water resource utilization, which reflected the characteristics of the mutual influence of

Table 2. Comparison of comprehensive scores of different evaluation methods.

Project No.	1	2	3	4	5
Traditional evaluation comprehensive score	3.1	3.3	2.9	3.3	3.4
Fuzzy comprehensive evaluation comprehensive score	4.0	4.2	3.8	4.1	4.2
Comprehensive score difference	0.9	0.9	0.9	0.8	0.8
Difference in environmental factor score ratio	0.06	0.07	0.06	0.06	0.07
Difference in landscape aesthetics score	0.03	0.04	0.03	0.04	0.03

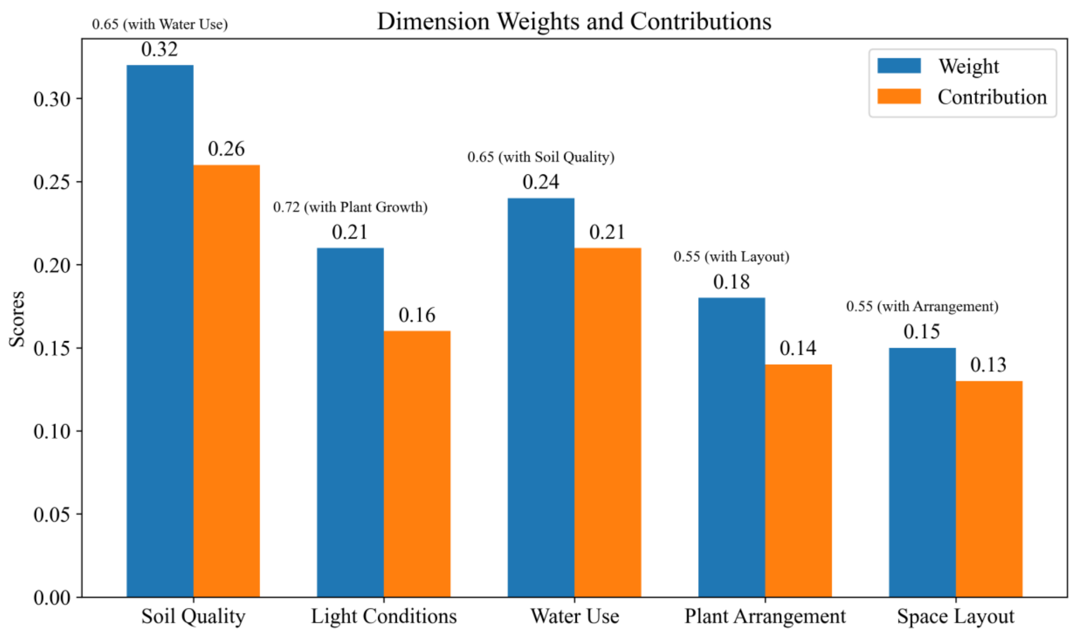

Figure 3. Weight distribution of each indicator in fuzzy comprehensive evaluation.

Table 3. Fluctuation of scores of various indicators in fuzzy comprehensive evaluation in different projects.

Project No.	1	2	3	4	5
Soil quality scores fluctuate	0.08	0.10	0.07	0.09	0.08
Lighting condition score fluctuations	0.04	0.05	0.04	0.05	0.04
Water use score fluctuations	0.06	0.06	0.06	0.06	0.06
Plant coordination score fluctuations	0.10	0.08	0.09	0.11	0.10
Spatial layout rationality score fluctuations	0.05	0.04	0.05	0.04	0.05

various factors in the ecosystem. The analysis of the contribution of the comprehensive score showed that different indicators had different degrees of influence on the comprehensive score, which provided a reference for further optimizing the evaluation system (Figure 3). The fluctuations in the scores of each indicator of fuzzy comprehensive evaluation in different projects showed that the soil quality score fluctuated relatively little, indicating that the differences in soil quality among different projects were relatively stable, while the plant coordination score fluctuated relatively high, which might be due to the different design concepts and plant selections of different projects (Table 3). By analyzing the fluctuations, the stability of different projects in each indicator could be understood, and understanding these

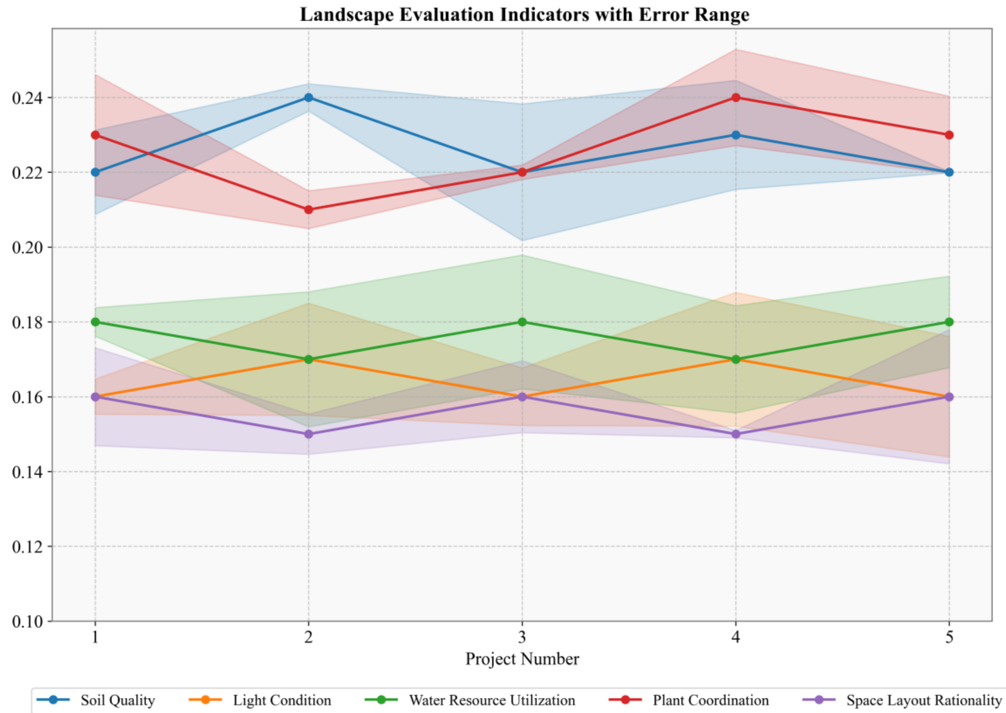

Figure 4. Subjective deviation analysis of each indicator of traditional evaluation method.

fluctuations could help to focus on and optimize relevant indicators in practical applications.

The subjective bias of each indicator in the traditional evaluation method

The results showed that the traditional evaluation method had a certain degree of subjective bias in each indicator, which was because it mainly relied on expert experience and qualitative judgment, lacking objective data support and quantitative analysis (Figure 4). Large subjective bias might lead to inaccurate and unreliable evaluation results, while the fuzzy comprehensive evaluation method effectively reduced this subjective bias through scientific quantitative means.

Performance comparison of different evaluation methods in different scale projects

Regardless of the size of the project, the score of the fuzzy comprehensive evaluation method was significantly higher than that of the traditional evaluation method. In terms of the difference in environmental factor scores, large projects were relatively high, which might be because the environmental factors of large projects were more complex, and the fuzzy comprehensive evaluation method had a more significant advantage in dealing with complex environmental factors. The difference in landscape aesthetics scores was relatively stable in projects of different scales, indicating that the advantage of the fuzzy comprehensive evaluation method in landscape aesthetics evaluation was not affected by the project scale (Table 4).

Comparison of the climatic effects on different evaluation methods

In different climate types, the scores of the fuzzy comprehensive evaluation method were higher than those of the traditional evaluation method. In terms of the difference in environmental factor scores, the tropical monsoon climate was relatively high, which was because the environmental conditions of the tropical monsoon climate were more complex and diverse, and the fuzzy comprehensive evaluation

Table 4. Performance comparison of fuzzy comprehensive evaluation and traditional evaluation methods in projects of different scales.

Project scale	Small	Medium	Large
Traditional evaluation average score	3.2	3.3	3.4
Fuzzy comprehensive evaluation average score	4.1	4.2	4.3
Score Difference	0.9	0.9	0.9
Environmental factors score difference	0.5	0.5	0.6
Difference in landscape aesthetics score	0.3	0.3	0.2

Table 5. Comparison of the climatic effects on fuzzy comprehensive evaluation and traditional evaluation methods.

Monsoon climate type	Temperate	Subtropical	Tropical
Traditional evaluation average score	3.2	3.3	3.4
Fuzzy comprehensive evaluation average score	4.1	4.2	4.3
Score Difference	0.9	0.9	0.9
Environmental factors score difference	0.5	0.5	0.6
Ecological function score difference	0.3	0.3	0.2

method could better adapt to this complexity and accurately evaluate environmental factors. The difference in ecological function scores also varied under different climatic conditions, reflecting the differences in the response of ecosystems to evaluation methods under different climatic conditions (Table 5).

The advantages of the fuzzy comprehensive evaluation method in different application scenarios

The proposed fuzzy comprehensive evaluation method demonstrated that, in the urban park scenario, the accurate assessment of environmental carrying capacity increased by 25%, the landscape aesthetics optimization index was 1.3, the quantitative ecological function promoted sustainable development by 20%, the efficiency of effective integration of multi-source data increased by 30%, and the error margin of subjective judgment was reduced by 40%. In the greening of residential areas, the satisfaction of residents' demand for environmental comfort increased by 20%, the optimization index of community landscape quality was 1.2, the stability of the ecosystem was enhanced by 15%, the efficiency of data integration for residential areas of different sizes increased by 25%, and the coordination and unification with the surrounding environment reduced the subjective error by 35%. In the campus landscape, the creation of a good learning atmosphere increased the accurate assessment by 18%, the landscape aesthetics optimization index for promoting campus ecological education was 1.1, the ecological function of reasonable planning of spatial layout increased by 12%, the efficiency of data integration combined with campus cultural characteristics increased by 20%, and the long-term maintenance cost was controllable, which reduced the subjective error by 30% (Figure 5). This quantitative data reflected the significant advantages and effectiveness of the proposed fuzzy comprehensive evaluation method in different application scenarios. The results showed that the fuzzy comprehensive evaluation method had significant advantages in the evaluation of green design of ecological garden landscape. The evaluation scores in multiple dimensions were higher than those of traditional evaluation method because of its scientific quantitative analysis method. By constructing membership functions and determining weights, it could transform complex and fuzzy evaluation indicators into precise values, thereby more accurately reflecting the actual situation of ecological garden landscape. In terms of the external validity and generalizability, this

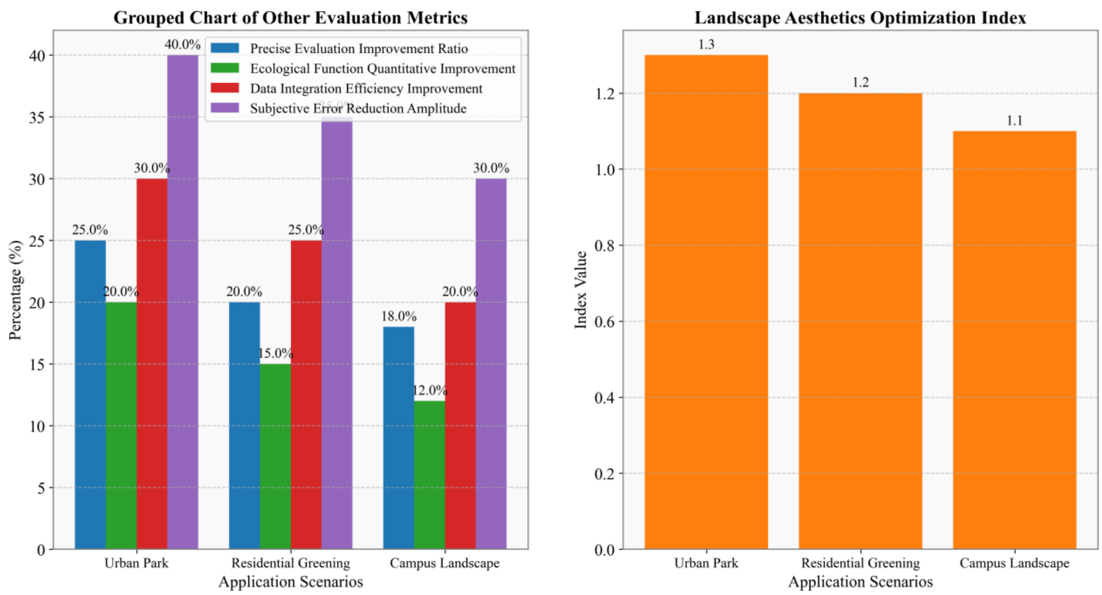

Figure 5. Quantitative analysis of the advantages of fuzzy comprehensive evaluation method in different application scenarios.

research selected multiple representative ecological garden landscape projects in different cities, scales, and climatic conditions and confirmed that the fuzzy comprehensive evaluation method had high generalizability in the evaluation of ecological garden landscape design in different regions and different types. However, there were still some possible biases and limitations in this research. When determining the weights, although scientific methods such as hierarchical analysis were used, the subjective judgment of experts might still have a certain impact on the results. In addition, there might be certain limitations in the collection of experimental data. Future research should further expand the scope of data collection and improve the accuracy and comprehensiveness of data.

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