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Evaluation Method of Green Building from the Perspective of Sustainable Development

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Abstract: This paper takes green buildings as the research object, and evaluates the comprehensive benefits of green buildings. Firstly, from the perspective of system, its green building evaluation system is divided into three aspects, including economic benefits, environmental benefits and social benefits. Then, the principal component analysis (PCA) is used to analyze the survey results, and 20 representative and important influencing factors are selected. Finally, the analytic hierarchy process (AHP) is used to determine the index weight, and the comprehensive benefit evaluation model of green building based on AHP-matter-element extension model is established. The practice shows that the green building evaluation model built in this paper is beneficial to the design and optimization of green building energy-saving technical scheme, enriches the research content of green building benefits, and further reflects the advantages and feasibility of green building performance.

1. Introduction

As a large user of resource consumption and environmental pollution, the construction industry uses nearly 50% of land resources, stone resources and wood resources every year. At the same time, the energy consumption of building air conditioning, lighting and ventilation systems accounts for 45% of the total energy consumption of the society. The construction and operation stages require a large amount of water resources support, accounting for 16% and 40% of the total water consumption of the society, respectively [1]. It is the first to realize the importance of practicing green and environmentally friendly buildings. As the main output of the green environmental protection concept, green buildings should be guided to improve the use efficiency of resources and reduce the pollution to the environment as much as possible during the whole life cycle of buildings such as design, construction, operation and demolition, so as to provide users with a comfortable and safe indoor environment. Developing green buildings has become the main method and means to solve building energy consumption and environmental problems in various countries [2].

This paper defines the composition of the comprehensive benefits of green buildings, determines the influencing factors of the comprehensive benefits of green buildings, establishes the indicator system of the comprehensive benefits of green buildings on the basis of the influencing factors, and constructs the evaluation model of the comprehensive benefits of green buildings using the matter-element extension theory [3]. Finally, the validity of the model is verified by the green building engineering example, in order to provide reference for the future development of green buildings.

2. Green Building Design under the Concept of Sustainable Development

2.1 Green Building Design Concept

Green buildings refer to high-quality buildings that can save energy, reduce environmental pollution, provide people with healthy, applicable and efficient use space, and maximize the harmonious coexistence of human and nature in the whole life cycle. With the revision of the Green Building Evaluation Standard (GB/T 50378-2019), the concept of green building is gradually reflected in the urbanization construction, mainly in the following aspects [4]:

a) Energy conservation. The design of green buildings should consider the layout comprehensively according to the geographical environmental conditions, climatic conditions and surrounding adjacent buildings of the project site, so as to achieve the purpose of reducing the energy consumption of its own buildings by using natural resources. For example, the use of wind farms, solar energy, rain and other resources.

b) Harmonious coexistence of human, nature and architecture. At the initial stage of design, green buildings should pay attention to harmony with the environment and make the best use of the surrounding environment of the project site. In addition, in the construction process, they need to complement each other with the natural environment to achieve effective protection of the ecological environment [5]. On the other hand, the interior design of green buildings needs to consider saving building materials, decoration materials, facilities and appliances, and control their impact on the environment and indoor air. More importantly, the interior design needs to meet the psychological suitability, and then pursue a healthy, comfortable and clean living space.

c) Saving resources. Green buildings are called green buildings only when the health of users is put first and the resource conservation is concerned, and the impact on the ecological environment is reduced as much as possible. Its main characteristics are pleasant environment and comfort. From this point, we can see that green buildings must use resources scientifically in the design, so as to achieve four saving and one environmental protection.

In terms of the above green building design concepts, green buildings have the following characteristics: first, the design of green buildings needs to put people's comfort in the first place. Only by providing a good living environment can we realize the harmonious development of man and nature; second, green building design needs to consider the regional characteristics, that is, adjust the building design strategy appropriately according to the regional climate, terrain, culture, resources and other characteristics, so as to maximize the goal of building energy conservation; third, the concept of three-dimensional greening should be widely used. Three-dimensional greening can improve the thermal environment, save energy, reduce noise, purify air, aesthetic vision and other values. These values implicitly correspond to the purpose of green buildings, which is also one of the development trends of green buildings. Under the siphon mode of megacities, the garden green space is gradually eroded, leading to the increasingly prominent heat island effect, and the frequent occurrence of flood disasters, making three-dimensional greening an effective remedy.

2.2 Green Building Evaluation Standard

Since modern times, the gradual deterioration of the ecological environment has made forward-looking countries pay great attention. Therefore, in order to change this situation, western developed countries began to develop green buildings. In order to implement the concept of green building and test the actual effect of green building [6], countries around the world have formulated green building evaluation standards suitable for their own characteristics to guide green building practice, as shown in Table 1.

Table 1: Main National Green Building Evaluation Standards.

Year	Country	Evaluation criterion	Main features
1990	England	Building Research Establishment Environmental Assessment Method (BREEAM)	a) The first practical standard; b) Leading the world; c) One of the widely used evaluation criteria.
1998	United States	Leadership in Energy and Environmental Design (LEED)	a) has the largest promotion and global influence; b) Leading standard for green building development.
1998	Canada	Sustainable building tool (SB tool)	a) International universality; b) Strong research and regional flexibility; c) Provide a relatively unified comparison platform for the green evaluation standards of countries around the world.
2001	Japan	Comprehensive Assessment System for Building Environmental Efficiency (CASBEE)	a) The first evaluation standard issued by Asia; b) The indicator system is too complex and difficult.
2003	Australia	National Australian Built Environment Rating Scheme (NABERS); GREEN STAR	a) Detailed division of evaluation indicators; b) Draws on BREEAM and LEED; c) Focus on environmental issues.
2005	Singapore	GREEN MARK	a) Domestic mandatory standards must reach the lowest level; b) International use; c) It can help to improve our standards.
2008	Germany	Deutsche Gütesiegel für Nachhaltiges Bauen (DGNB)	a) There are many levels of evaluation and the difficulty of rating is low; b) International use; c) There are many types of building certification.

The development of green buildings in China lags behind that of western countries. It is gratifying to note that after decades of rapid development, the number of green buildings in China is increasing, and the evaluation criteria are gradually improved. In recent years, the research on green buildings has been hot for a long time. Undoubtedly, with the high-quality development of society, the old standards will gradually fail to adapt to the emergence of new technologies and meet the latest requirements. Therefore, the revision of the new standard is to meet the needs of the development of the times, so as to break the problem barriers faced by the old standard. The revision of the green building evaluation standard adjusts the indicator system, grade setting, evaluation rules and other aspects to create a new green building evaluation system, further expand the coverage of green buildings, and promote the development of green buildings to a higher level [7].

In 2019, China issued the Green Building Evaluation Standard (GB/T 50378-2019), which was officially implemented on August 1 of that year. This standard pays more attention to "people-oriented, performance stressed, quality improved, energy saving, information technology", and at the same time, a small number of provisions of the old standard are still used, with appropriate additions and changes, making the evaluation content more scientific and reasonable, and more consistent with contemporary development.

In this standard, resource conservation is the main consideration of green buildings. On the other hand, energy conservation design of green buildings is more important than land, water and material conservation design, and is also the top priority in sustainable development [8]. It is very important to do a good job of energy-saving design in the design stage of energy-saving buildings, but it is worth pondering how to do a good job of energy-saving design according to the 2019 green building evaluation standard.

3. Evaluation Index System for Green Building

3.1 Principles of Evaluation Indicators

In the study of comprehensive benefit evaluation of green buildings, the construction of the evaluation index system is the core link. The objective perfection of the evaluation system directly affects the accuracy and scientificity of the evaluation results. In order to ensure the reference of this study, the construction of the comprehensive benefit evaluation index system needs to follow the following principles:

a) Principle of scientific rationality. During the construction of the evaluation system, it is necessary to follow the objective facts and the laws of the building benefit itself, combine the basic theory of green building and the current development situation, define the target range, and select the indicator elements with evidence around the target range, so as to establish a scientific and reasonable indicator system.

b) Principle of systematic comprehensiveness. This paper carries out evaluation research from the perspective of comprehensive benefits of green buildings, mainly including economic, environmental and social aspects, and selects AHP method to determine the weight [9]. Based on the above background, when selecting indicators, it is necessary to consider comprehensive benefits as a system, comprehensively explore the indicator elements covering economic, environmental and social aspects, and ensure the integrity of the indicator elements, so as to build a systematic and comprehensive benefit bidding system.

c) Principle of operability. When selecting evaluation indicator elements, we need to consider whether their sources are easy to obtain and whether the indicator elements can be measured. We can judge whether the indicator elements have these attributes through actual cases, consulting relevant data, expert questionnaires and other methods, and select the indicator elements that meet the operability principle.

d) Principle of practicality. The research significance of this paper is to provide reference value and further promote green buildings. Based on the research significance and the conceptual scope of comprehensive benefits, it is necessary to establish a corresponding evaluation index system. Combining with actual cases and regional characteristics, select practical index elements to build an index system.

3.2 Comprehensive Evaluation Index System

This paper follows the above principles for the construction of the indicator system, combined with the screening and analysis results of the factors affecting the benefits from the three aspects of green building economy, environment and society, and takes the influencing factors as the source of the indicator elements to build the green building comprehensive benefit indicator system.

3.2.1 Economic Benefit Evaluation Index

The economic benefits of green buildings are mainly reflected in the two aspects of energy saving and resource saving benefits [10]. At the same time, they are also important to investment developers and consumers, and are supported by the government's incentive policies. Government incentives belong to direct economic benefits, but according to the transfer principle of national economic evaluation, they will not be used as the evaluation index of this economic benefit. The evaluation indicators of economic benefits of green buildings are shown in Table 2.

Table 2: Economic Benefit Evaluation Index.

Criterion layer	Primary indicator layer	Secondary indicator layer
Economic benefits A_1	Energy saving benefits B_1	High-performance enclosure structure C_1
		Efficient energy-using equipment and system C_2
		Renewable energy utilization C_3
	Water-saving benefit B_2	Water-saving appliances and equipment C_4
		Non-traditional water source utilization C_5
	Material saving benefit B_3	Obtain raw material locally C_6
		High performance materials C_7
	Land saving benefit B_4	Site planning and design C_8
		Permeable ground pavement C_9

3.2.2 Environmental Benefit Evaluation Index

The environmental benefits of green buildings are mainly reflected in the reduction of pollutants, improvement of indoor and surrounding environment, improvement of people's health, reduction of medical expenses, and extension of the service life of buildings and equipment. The reduction of noise pollution, the improvement of indoor environment and the number of repairs can all be reflected in the health of residents and the cost of building maintenance, so it is no longer used as an independent indicator of environmental benefits. To sum up, the evaluation index system of environmental benefits is shown in Table 3.

Table 3: Environmental Benefit Evaluation Index.

Criterion layer	Primary indicator layer	Secondary indicator layer
Environmental benefit A_2	Pollutant emission reduction benefits B_5	CO_2 emission reduction C_{10}
		Sewage treatment rate C_{11}
	Health benefits B_6	Building greening rate C_{12}
		Green building materials C_{13}
		Residents' health level C_{14}
	Benefits of building life extension B_7	Building maintenance cost C_{15}
		Outdoor environmental quality C_{16}

3.2.3 Social Benefit Evaluation Index

The social benefits of green buildings mainly drive the industrial development of surrounding areas through the development of green buildings, provide more employment and entrepreneurship opportunities, enhance people's awareness of energy conservation and environmental protection, alleviate the energy crisis, enhance social harmony, and at the same time provide residents with considerable livable benefits, provide people with healthy and comfortable life and work space, improve work efficiency, ensure people's physical and mental health, and create more additional creativity, Meet the growing material and cultural needs. Among them, the awareness of energy conservation and environmental protection is difficult to operate and quantify the results. The comfort of living environment can be reflected in the indicators for improving work efficiency, so it will not appear as an evaluation indicator alone. The evaluation index system of social benefits is shown in Table 4.

Table 4: Social Benefit Evaluation Index.

Criterion layer	Primary indicator layer	Secondary indicator layer
Social benefits A_3	Regional economic growth benefits B_8	Relevant industry driving rate C_{17}
		Financial expenditure saving C_{18}
	Residents' livable welfare B_9	Annual income level of residents C_{19}
		Work efficiency improvement C_{20}

4. Construction of Green Building Evaluation Model

4.1 Comprehensive Evaluation Index System

The comprehensive benefit evaluation research of green buildings has the characteristics of multi-angle, multi-attribute and multi-objective, and the factors affecting the comprehensive benefit of green buildings are also complex and diverse. The process of evaluation research also includes quantitative and qualitative data, so the simple objective weighting method cannot be used when calculating the weight of its evaluation indicators. In this paper, analytic hierarchy process (AHP) is used to determine the weight of the above green building evaluation indicators, and the specific steps are as follows:

(1) Determine the hierarchy model

First, clarify the research objectives, research scope and the factors included in the research questions, then clarify the relevance and affiliation between the factors, organize the research questions from top to bottom, and build a hierarchical structure model.

(2) Construction of judgment matrix

The importance of each factor under the same criteria level is not necessarily the same. Generally, the paired comparison method and the “1-9” scale method are used to compare the importance of the two factors. The evaluation system in this paper has a total of 20 evaluation indicators, which are evaluated and assigned according to the “1-9” scale method to obtain the judgment matrix A as follow:

$$A=(a_{ij})_{20\times 20}=\begin{vmatrix} a_{1,1} & a_{1,2} & \cdots & a_{1,20} \\ a_{2,1} & a_{2,2} & \cdots & a_{2,20} \\ \vdots & \vdots & \ddots & \vdots \\ a_{20,1} & a_{20,2} & \cdots & a_{20,20} \end{vmatrix} \tag{1}$$

(3) Solve the judgment matrix

Solve the maximum eigenvalue $\lambda_{\max}$ and eigenvector ω of the judgment matrix. The calculation methods include power method, sum method and square root method.

(4) Hierarchical order and consistency check

According to the weight results, the index $C_i\ (i=1,2,\ldots,20)$ of the upper layer structure B_i as the criterion layer is ranked in importance. The construction of judgment matrix itself is obtained by experts' scoring. Depending on the professional ability and experience of experts, there may be some subjectivity and error. The consistency test verifies the coordination of decision-makers' thinking and improves the accuracy of judgment. The consistency check formula is as follows:

$$CR=\frac{CI}{RI}=\frac{\lambda_{\max}-n}{RI(n-1)} \tag{2}$$

In the above formula, RI is a random consistency index, and its specific values are shown in Table 5.

Table 5: Random Consistency Index Value.

Matrix order	3	4	5	6	7	8	9	10
RI	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

(5) Total hierarchical sorting

Assume that the criterion layer has indicators $X_1, X_2, \ldots, X_n$, and the corresponding weights of the highest target layer are $x_1, x_2, \ldots, x_n$. Select an indicator X_i, and the corresponding weights of the scheme layer indicators $Y_1, Y_2, \ldots, Y_m$ with Xi as the criterion layer are $y_1, y_2, \ldots, y_m$. The formula for calculating the total ranking weights of the indicators in the remaining scheme layers is as follows:

$$Z_j = \sum_{i=1}^{n} x_i y_{ij} \quad (j = 1, 2, \ldots, m) \tag{3}$$

Finally, the total ranking weight of all scheme level indicators is as follows:

$$Z_j = (z_1, z_2, \ldots, z_k)^T \tag{4}$$

4.2 Evaluation Steps of Matter-Element Extension Model

(1) Determine the benefit evaluation level

The establishment of matter-element extension model needs to be divided into reasonable benefit evaluation grades. The comprehensive benefit evaluation index system of green buildings is composed of qualitative and quantitative indicators, which need to be comprehensively and systematically evaluated.

According to the relevant regulations, standards and references of green buildings, as well as practical cases, combined with the principles of qualitative and quantitative analysis, this paper divides the benefit evaluation grade into five grades: “poor, slightly poor, medium, good, and excellent”, and the corresponding grade interval is (0, 55], (55, 65], (65, 75], (75, 85], (85, 100], and constructs the classic field, section field and the subject element to be evaluated in the matter-element extension model according to the evaluation grade.

For the quantitative indicators in the indicator system, the classical domain and section domain are established according to the actual data. For the qualitative indicators, the classical domain and section domain of the qualitative indicators are determined by quantifying the qualitative indicators according to the grade interval in combination with the actual application of green technology.

(2) Determine the matter element to be evaluated

Take the research object N as the object to be evaluated, and the matter element formed by this feature is called the evaluation matter element. The matter element matrix R_0 is established according to the data value of each index of the matter element to be evaluated:

$$R_0 = (N_0, C_i, V_i) = \begin{bmatrix} N_0 & C_1 & V_1 \\ & C_2 & V_2 \\ & \vdots & \vdots \\ & C_n & V_n \end{bmatrix} \tag{5}$$

In the formula, N_0 is the evaluated object; V_i is the value corresponding to evaluation feature C_i.

(3) Determine classic domain

The matter element of the classical domain refers to the range of values contained by the matter N with respect to part of the feature C. Let the evaluation object N, the classic domain matter element R_j of the *j*-th evaluation level is as follows:

$$R_j=(N_j,C_j,V_{ji})=\begin{bmatrix} N_j & C_1 & V_{j1} \\ & C_2 & V_{j2} \\ & \vdots & \vdots \\ & C_n & V_{jn} \end{bmatrix}=\begin{bmatrix} N_j & C_1 & [a_{j1},b_{j1}] \\ & C_2 & [a_{j2},b_{j2}] \\ & \vdots & \vdots \\ & C_n & [a_{jn},b_{jn}] \end{bmatrix} \tag{6}$$

In the formula, N_j is the *j*-th evaluation grade of the rating object; $V_{ji}=[a_{ji},b_{ji}]$ is the interval range of C_i corresponding to the *j*-th evaluation grade.

(4) Determine section domain

The segment matter-element refers to the value range contained by the event N with respect to all features C. For the evaluation object N, the nodal matter element R_p of all evaluation grades is as follows:

$$R_p=(N_p,C_j,V_{pi})=\begin{bmatrix} N_p & C_1 & V_{p1} \\ & C_2 & V_{p2} \\ & \vdots & \vdots \\ & C_n & V_{pn} \end{bmatrix}=\begin{bmatrix} N_p & C_1 & [a_{p1},b_{p1}] \\ & C_2 & [a_{p2},b_{p2}] \\ & \vdots & \vdots \\ & C_n & [a_{pn},b_{pn}] \end{bmatrix} \tag{7}$$

(5) Determine correlation function

The correlation function is a function used to determine the correlation value of the benefit grade. The specific calculation formula is as follows:

$$K_j(V_i)=\begin{cases} -\dfrac{\rho\left(v_i,v_{ji}\right)}{\left|v_{ji}\right|}, & v_i\in v_{ji} \\ \dfrac{\rho\left(v_i,v_{ji}\right)}{\rho\left(v_i,v_{pi}\right)-\rho\left(v_i,v_{ji}\right)}, & v_i\notin v_{ji},\ \rho\left(v_i,v_{ji}\right)\neq 0 \\ -\rho\left(v_i,v_{ji}\right)-1,\ v_i\notin v_{ji}, & \rho\left(v_i,v_{ji}\right)=0 \end{cases} \tag{8}$$

In the formula, $K_j(V_i)$ is the correlation function value of the *i*-th evaluation index with respect to the *j*-th evaluation grade.

(6) Calculate the comprehensive correlation degree

The comprehensive correlation degree $K_j(N_0)$ of the object N to be evaluated with respect to grade j is calculated as follows:

$$K_j(N_o)=\sum_{i=1}^{n}\omega_i K_j(V_i),\quad i=1,2,\ldots,n \tag{9}$$

(7) Determine the benefit evaluation grade of the object to be evaluated

According to the comprehensive correlation degree value, the corresponding benefit evaluation grade of the object *N* to be evaluated can be determined as follows:

$$K_j(N_o)=\max K_j(N_o),\qquad j=1,2,\ldots,n \tag{10}$$

In the formula, the maximum value of K_j is the benefit evaluation grade. According to the principle of maximum membership, the benefit evaluation grade corresponding to the maximum value is the benefit evaluation result of the example project.

5. Conclusions

Green building, as the primary direction of the transformation, upgrading and development of China's construction industry, has brought benefits that cannot be underestimated. This paper takes the comprehensive benefits of green building as the research object, uses the principal component analysis method to screen the influencing factors and indicators, constructs the comprehensive benefit evaluation index system, and establishes the matter-element extension model for benefit evaluation on this basis.

Using matter-element extension theory to establish an evaluation model for the comprehensive benefit of the project, we can discard the subjectivity of AHP in determining the weight, and obtain the evaluation grade of the comprehensive benefit of the project, as well as the economic, social and environmental benefits, and even the evaluation grade of the first-level and second-level indicators. The evaluation results are consistent with the actual situation, which verifies the effectiveness of the model and the clear results. It is convenient to analyze and draw more targeted suggestions, making the research on comprehensive benefit evaluation of green buildings more practical.

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