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Research on fuzzy comprehensive evaluation method of green building

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ABSTRACT

Currently, sustainability has become a global strategy of human society, in which the development of green building the one of the most significant aspects. However, the evaluation of green building is an obvious challenge. This paper proposed a green building evaluation index system of green building, with a fuzzy comprehensive evaluation method being given. The research on fuzzy comprehensive evaluation method has important theoretical and practical meanings for enriching and developing techniques and methods of green building evaluation, which may facilitate healthy and rapid development of green building.

Key words: Green building；Fuzzy；Evaluation method

INTRODUCTION

Green building means the reform of traditional building in design, construction and use, focusing on efficient use of resources and energy, harmless and economical applications of construction materials and methods, high-quality living environment, and respect of local architectural history. From the practical perspective, it is urgent to establish a scientific and reasonable evaluation system for meeting the design and construction goals of green building, and actively guiding the development of green building. The evaluation of green buildings is multi-factor, multi-level, multi-objective and complex problems, so it is difficult to obtain a good evaluation results by simple evaluation method. Based on fuzzy mathematics theory, this research established a fuzzy comprehensive model of green building, with evaluation methods proposed, which may provide a more practical framework for the evaluation of green building.

EVALUATION INDEX SYSTEM

1. Levels of Evaluation Index System

According to the features and contents of green building, the evaluation indexes system can be divided into four levels-goal, targets, criterion and indexes. The hierarchy of indexes system is shown in Fig. 1.

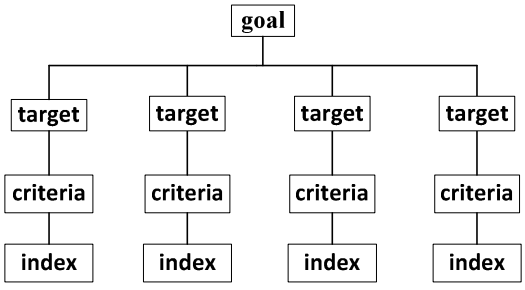

Fig.1 The hierarchy of indexes system.

2. Establishment of Evaluation Indexes System

The goal of green building evaluation can be divided into three targets-environmental target, economic target and social target. The targets can be further subdivided into evaluation criterion and indexes. The selection of indexes should be based on the goal of green building evaluation, at the same time, meeting the constraints and requirements of the criterion. The established indexes should be representative, accurate and effective.

The criterion and indexes of environmental target, economic target and social target are as follows[1].

2.1. Criterion and indexes of environmental target

The criterion of environmental target can be defined as "Surrounding Environmental Governance(SEG)", "Indoor Environmental Quality(IEQ)" and "Regional Environmental Improvement(REI)". The three criterion can be further broken down into a number of indexes.

- The indexes of criterion "surrounding environmental governance": Surrounding environmental governance include air, water, solid waste and noise pollution control, so the indexes can be set as "Atmospheric Environmental Governance(AEG)", "Water Environmental Governance(WEG)", "Noise Pollution Control (NPC)" and "Ability of Solid Waste Disposal (ASWD)".
- The indexes of criterion "indoor environmental quality": Indoor environmental quality include comfortable building space, good indoor physical environment and indoor sanitary conditions, so the indexes can be set as "Indoor Space Environment (ISE)", "Indoor Air Quality (IAQ)", "Indoor Lighting and Ventilation (ILV)" and "Indoor Sanitation (IS)".
- The indexes of criterion "regional environmental improvement": Regional environmental improvement refers to the implementation of environmental protection measures for improving the quality of the regional ecological environment. The indexes can be set as "Ability to Maintain Ecological Balance (AMEB)", "Conservation of Biological Diversity (CBD)" and "Proportion of Environmental Protection Investment (PEPI)".

2.2. Criterion and Indexes of Economic Target

Economic target is mainly reflected in the economic benefits of land utilization and application of green building materials, and reducing life-cycle cost of building. Therefore, the criterion of economic target can be defined as "Benefits of Land Utilization (BLU)", "Application of Green Building Materials (AGBM)" and "Reduction of Life-Cycle Cost (RLCC)". The indexes corresponding to different criterion are as follows.

- The indexes of criterion "benefits of land utilization": This criterion includes two meanings, firstly, green building can enhance the value of the construction land; secondly, land conservation measures must be taken for intensive use of land resources. The indexes can be set as "Effectiveness of Land Use (ELU)" and "Enhancing Value of Construction Land (EVCL)".
- The indexes of criterion "application of green building materials": The related indexes of green building materials can be divided into "Transport Distance of Building Materials (TDBM)", "Proportion of Recycled Materials (PRM)" and "Durability of Building Materials (DBM)".
- The indexes of criterion "reduction of life-cycle cost": Life-cycle cost refers to the construction cost and the cost of operation and maintenance. The related indexes of life-cycle cost can be divided into "Construction Cost (CC)" and "Operation and Maintenance Cost (OMC)".

2.3. Criterion and Indexes of Social Target

The criterion of social target can be divided into "Maintenance of Regional Features (MRF)" and "Improvement of Living Situation (ILS)". The related indexes are as follows.

- The indexes of criterion "maintenance of regional features": The corresponding indexes can be defined as "Organic Combination with Regional Features (OCRF)", "Historical Landscape Preservation (HLP)", "Harmony of Architectural Pattern (HAP)" and "Creation of Regional New Landscape (CRNL)".
- The indexes of criterion "improvement of the living situation": The corresponding index can be expressed as "Per Capita Living Space (PCLS)".

Evaluation index system of green building is shown in Table 1, and all the indexes are expressed as the shortened form.

Table 1. Evaluation Index System of Green Building

Targets	Criterion	Indexes
Environmental Target	SEG	AEG WEG NPG ASWD
	IEQ	ISE IAQ ILV IS
	REI	AMEB CBD PEPI
Economic Target	BLU	ELU EVCL
	AGBM	TDBM PRM DBM
	RLCC	CC OMC
Social Target	MRF	OCRF HLP HAP CRNL
	ILS	PCLS

DEVELOPMENT OF FUZZY COMPREHENSIVE EVALUATION MODEL

General steps of establishing fuzzy comprehensive evaluation model of green building are as follows.

1. Determining the Set of Evaluation Factors

According to the factors that affect the level of green building, the set of evaluation factors can be determined by principal component analysis or cluster analysis.

$$U=\{u_1,u_2,\cdots,u_m\} \tag{1}$$

If evaluation factors are composed of targets, criterion and indexes, the set of factors can be divided into several subsets, and the subsets meet the following conditions.

$$\sum_{i=1}^{m}U_i=U,U_i\bigcap U_j=\varnothing(i\neq j) \tag{2}$$

2. Determining Evaluation Scale Set

Evaluation scale set is composed of a variety of evaluation results.

$$V=\{v_1,v_2,\cdots,v_n\} \tag{3}$$

3. Establishing the weight set

$$W=(w_1,w_2,\cdots,w_m),0\le w_i\le 1,\sum_{i=1}^{m}w_i=1 \tag{4}$$

In order to reflect the importance of various factors, the weight set of evaluation factors can be determined by use of expert scoring method or AHP.

4. Establishing decision matrix

According to the determined evaluation scale, evaluation factors can be evaluated, which is actually a fuzzy mapping, and the decision matrix can be established.

$$R=\begin{pmatrix} R_1 \\ R_2 \\ \vdots \\ R_m \end{pmatrix}=\begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{pmatrix} \quad (5)$$

R is a set of fuzzy relations from set U to set V. In the matrix R, $r_{ij}=\frac{d_{ij}}{d}$, among which d_{ij} is the number of experts making evaluation v_j of the factor u_i, and d is the number of experts participating in the evaluation.

5. Calculating evaluation vector set of single evaluation factors subset

For the multi-evaluation, the evaluation process can be divided into several steps. For each evaluation factors subset U_i, if it's weight set is w_i, and decision matrix is R_i, then the evaluation result is showed in formula (6).

$$B_i=w_i\mathrm{R}_i=[b_{i1},b_{i2},\cdots,b_{in}] \quad (6)$$

Then, evaluation factors subsets $U_i\ (i=1,2,\cdots,m)$ can be comprehensive evaluated, getting the evaluation matrix R of the evaluation factors set U.

$$R=\begin{pmatrix} B_1 \\ B_2 \\ \vdots \\ B_m \end{pmatrix}=\begin{pmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ b_{m1} & b_{m2} & \cdots & b_{mn} \end{pmatrix} \quad (7)$$

6. Calculating fuzzy comprehensive evaluation vector set of green building

$$B=WR=(w_1,w_2,\cdots,w_m)\begin{pmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ b_{m1} & b_{m2} & \cdots & b_{mn} \end{pmatrix}=(b_1,b_2,\cdots,b_n) \quad (8)$$

7. Calculating the level of green building

$$L=BV=(b_1,b_2,\cdots,b_n)\begin{pmatrix} v_1 \\ v_2 \\ \vdots \\ v_n \end{pmatrix} \quad (9)$$

THE EVALUATION PROCESS

Based on the establishment of evaluation indexes system and evaluation model, the fuzzy comprehensive evaluation process of green building is as follows.

1. Parameterization of evaluation indexes

According to previously established evaluation indexes system of green building and fuzzy comprehensive evaluation model, parameterized evaluation indexes system of green building is shown in Table 2.

Table 2. Parametrization of evaluation index system.

Overall objective	Sub-objectives	W^t	Criteria	W_i^t	Indexes	W_{ij}^t
Level Of Green Building (L)	Environmental Sub Objectives (U^1)	w^1	S E G(U_1^1)	w_1^1	AEG(U_{11}^1)	w_{11}^1
					WEG(U_{12}^1)	w_{12}^1
					NPG(U_{13}^1)	w_{13}^1
					ASWD(U_{14}^1)	w_{14}^1
			IEQ(U_2^1)	w_2^1	ISE(U_{21}^1)	w_{21}^1
					IAQ(U_{22}^1)	w_{22}^1
					ILV(U_{23}^1)	w_{23}^1
					IS(U_{24}^1)	w_{24}^1
			REI(U_3^1)	w_3^1	AMEB(U_{31}^1)	w_{31}^1
					CBD(U_{32}^1)	w_{32}^1
					PEPI(U_{33}^1)	w_{33}^1
	Economic Sub Objectives (U^2)	w^2	BLU(U_1^2)	w_1^2	ELU(U_{11}^2)	w_{11}^2
					EVCL(U_{12}^2)	w_{12}^2
			AGBM(U_2^2)	w_2^2	TDBM(U_{21}^2)	w_{21}^2
					PRM(U_{22}^2)	w_{22}^2
					DBM(U_{23}^2)	w_{23}^2
			RLCC(U_3^2)	w_3^2	CC(U_{31}^2)	w_{31}^2
					OMC(U_{32}^2)	w_{32}^2
	Social Sub Objectives (U^3)	w^3	MRF(U_1^3)	w_1^3	OCRF(U_{11}^3)	w_{11}^3
					HLP(U_{12}^3)	w_{12}^3
					HAP(U_{13}^3)	w_{13}^3
					CRNL(U_{14}^3)	w_{14}^3
			ILS(U_2^3)	w_2^3	PCLS(U_{21}^3)	w_{21}^3

The meaning of each parameter is described as follows.

U^t - Sub-objectives

w^t - Weight for the i-th factor

U_i^t - Criteria corresponding with t-th sub objective

w_i^t - Weight corresponding with the evaluation factors U_i^t

U_{ij}^t -Indexes for the i-th index corresponding with t-th sub objective

w_{ij}^t - Weight corresponding with the evaluation indexes U_{ij}^t

The weight of evaluation indexes system must meet the following conditions.

$$\sum_{t=1}^{3} w^t = 1,\ \sum_{i=1}^{3} w_i^1 = 1,\ \sum_{i=1}^{3} w_i^2 = 1,\ \sum_{i=1}^{2} w_i^3 = 1, \sum_{j=1}^{4} w_{1j}^1 = 1, \sum_{j=1}^{4} w_{2j}^1 = 1, \sum_{j=1}^{3} w_{3j}^1 = 1, \sum_{j=1}^{2} w_{1j}^2 = 1$$

$$\sum_{j=1}^{3} w_{2j}^2 = 1, \sum_{j=1}^{2} w_{3j}^2 = 1, \sum_{j=1}^{4} w_{1j}^3 = 1, w_{21}^3 = 1$$

2. Determining the evaluation factors set:

$U = (U^1, U^2, U^3)$, $U^1 = (U_1^1, U_2^1, U_3^1)$, $U_1^1 = (U_{11}^1, U_{12}^1, U_{13}^1, U_{14}^1)$, $U_2^1 = (U_{21}^1, U_{22}^1, U_{23}^1, U_{24}^1)$, $U_3^1 = (U_{31}^1, U_{32}^1, U_{33}^1)$, $U^2 = (U_1^2, U_2^2, U_3^2)$, $U_1^2 = (U_{11}^2, U_{12}^2)$, $U_2^2 = (U_{21}^2, U_{22}^2, U_{23}^2)$, $U_3^2 = (U_{31}^2, U_{32}^2)$, $U^3 = (U_1^3, U_2^3)$, $U_1^3 = (U_{11}^3, U_{12}^3, U_{13}^3, U_{14}^3)$, $U_2^3 = (U_{21}^3)$

3. Determining the weight set of evaluation factors by use of expert scoring method or AHP:

$W = (w^1, w^2, w^3)$

$w^1 = (w_1^1, w_2^1, w_3^1)$, $w_1^1 = (w_{11}^1, w_{12}^1, w_{13}^1, w_{14}^1)$, $w_2^1 = (w_{21}^1, w_{22}^1, w_{23}^1, w_{24}^1)$, $w_3^1 = (w_{31}^1, w_{32}^1, w_{33}^1)$,

$w^2 = (w_1^2, w_2^2, w_3^2)$, $w_1^2 = (w_{11}^2, w_{12}^2)$, $w_2^2 = (w_{21}^2, w_{22}^2, w_{23}^2)$, $w_3^2 = (w_{31}^2, w_{32}^2)$,

$w^3 = (w_1^3, w_2^3)$, $w_1^3 = (w_{11}^3, w_{12}^3, w_{13}^3, w_{14}^3)$, $w_2^3 = (w_{21}^3)$

4. Determining the evaluation scale set:

$$V = \{v_1, v_2, v_3\}$$

The value of evaluation scale can be defined as $(good, medium, poor)$, corresponding scores as (0.9, 0.5, 0.3). According to the scores of the evaluation factors, the decision matrixes of evaluation factors are as follows.

$R_1^1 = (r_{1ij}^1)_{4\times3}$, $R_2^1 = (r_{2ij}^1)_{4\times3}$, $R_3^1 = (r_{3ij}^1)_{3\times3}$

$R_1^2 = (r_{1ij}^2)_{2\times3}$, $R_2^2 = (r_{2ij}^2)_{3\times3}$, $R_3^2 = (r_{3ij}^2)_{2\times3}$

$R_1^3 = (r_{1ij}^3)_{4\times3}$, $R_2^3 = (r_{2ij}^3)_{1\times3}$

5. Obtaining the evaluation results of U_i^1, U_i^2 and U_i^3:

$B_i^1 = w_i^1 R_i^1$, $(i = 1, 2, 3)$

$B_i^2 = w_i^2 R_i^2$, $(i = 1, 2, 3)$

$B_i^3 = w_i^3 R_i^3$, $(i = 1, 2)$

6. Obtaining the decision matrixes of U^1, U^2 and U^3:

$$R^1 = \begin{pmatrix} B_1^1 \\ B_2^1 \\ B_3^1 \end{pmatrix}, \quad R^2 = \begin{pmatrix} B_1^2 \\ B_2^2 \\ B_3^2 \end{pmatrix}, \quad R^3 = \begin{pmatrix} B_1^3 \\ B_2^3 \end{pmatrix}$$

7. Obtaining the evaluation results of U^1, U^2 and U^3:

$$B^1 = w^1 R^1, \quad B^2 = w^2 R^2, \quad B^3 = w^3 R^3$$

8. Obtaining the decision matrixes of U:

$$R = \begin{pmatrix} B^1 \\ B^2 \\ B^3 \end{pmatrix}$$

9.Calculating the overall evaluation results of green building：

$$B = WR = (w^1, w^2, w^3)\begin{pmatrix} B^1 \\ B^2 \\ B^3 \end{pmatrix} = (b_1, b_2, b_3)$$

10. Calculating the level of green building based on the evaluation scale set:

$$L = BV = (b_1, b_2, b_3)\begin{pmatrix} v_1 \\ v_2 \\ v_3 \end{pmatrix}$$

According to the evaluation results, the level of green building can be defined as good, medium or poor.

SUMMARY

The evaluation of green building is a multi-factor, multi-level, multi-objective and complex problem, so it is hard to obtain effective evaluation results by use of simple evaluation methods or model. Based on fuzzy mathematical theory, this paper established a fuzzy comprehensive evaluation model of green building and provided the detailed evaluation method. The results of research can provide a workable solution to the evaluation problem of green building.

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