Research on Evaluation of Eco-Metro Station Levels Based on Hierarchical Analysis Models

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Abstract: With the help of hierarchical analysis and fuzzy comprehensive evaluation theory, this paper innovatively constructs a hierarchical evaluation model of underground metro station ecological building projects from six aspects, namely, land saving, material saving, indoor environment, water saving, energy saving and operation management, and combines with the premise of spatial specificity and complexity of underground metro stations, so as to provide a theoretical basis for the development of ecological buildings in the construction of underground metro stations. The article selects the ecological building of underground station in Qingdao, China to carry out comprehensive evaluation and validation. The results of the study show that the evaluation model based on hierarchical analysis can effectively quantify the ecological grades of metro station projects.

1 Introduction

In the 1990s, the world's first green building standard was released in the United Kingdom, marking the emergence of a scientific quantitative assessment system for green building, and green building has since bid farewell to the theoretical era, begun to formally enter the historical arena, and ushered in the era of comprehensive development[1].

The connotation of green building can basically be summarised as energy saving, providing people with a comfortable and healthy living environment and harmonious coexistence with nature and sustainable development. Green buildings share the same objectives as eco-buildings and sustainable buildings, i.e. to conserve resources and provide a comfortable environment for people, but they also have different emphases. In terms of time, BREEAM is the earliest, followed by LEED, while China's green building evaluation system appears relatively late; in terms of coverage, BREEAM covers the widest range of buildings, including industrial, healthcare, education, office, community, residential and other types of buildings, while LEED covers a little less than BREEAM, and China's green building evaluation system is the most homogeneous.

The green building evaluation system in China is the most homogeneous, mainly for residential and public buildings; from the point of view of the level of certification, the three evaluation systems are also different, the BREEAM system is divided into five levels, which are Pass, Good, Excellent, Merit and Distinguished, the LEED system is divided into four levels, which are Certified, Silver, Gold and Platinum, and the green building evaluation system in China is divided into three levels, which are one-star, two-star and three-star, China's green building rating system is divided into three levels, namely one-star, two-star and three-star[2].

However, there are still problems in the determination of the weight of the indicators, which are currently widely used in China's main star certification field, but the standard has the drawbacks of obvious geographical differences and poor comprehensive analyses.

More importantly, the current green building evaluation system is mainly for aboveground buildings and their ancillary parts, due to the specificity and complexity of the underground station, these evaluation and design indicators often can not be directly used in the green design and evaluation of underground underground station space, such as the underground station space compared to the aboveground building itself meets the land-saving indicator, as well as aboveground buildings in the energy-saving envelope in addition to the consideration of materials, but also consider the window and wall area of the building, and the energy efficiency of the building[3].

In addition to the consideration of the material of the above ground building in the energy saving of the envelope in addition to the consideration of the window-wall area ratio, building orientation and other factors, while the underground station belongs to the underground space due to the deep underground, and the window opening is restricted, this control factor to consider and the above ground buildings are different, and more consideration of the material of the envelope and other factors, the building orientation of the underground

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building of the impact of the building is also basically negligible. This paper is the study of underground metro station space under the consideration of the special characteristics and complexity of the premise with the help of hierarchical analysis and fuzzy comprehensive evaluation theory, innovative construction of ecological building project level evaluation model, in order to provide a theoretical basis for the development of ecological building construction of metro station.

2 Construction of Evaluation Models for Ecological Building Projects

2.1 Construction of the Indicator System

The selection of eco-buildings indicators should follow five principles: systematic, quantitative and qualitative, scientific, hierarchical and feasibility[4]. The selection of eco-buildings indicators needs to take into account the whole life cycle of eco-buildings, i.e. planning, design, construction, operation and other stages of the indicators. Scholars at home and abroad have been studying the selection principles of these indicators, but no unified standard has been formed so far[5]. The structure and type of ecological building system are diversified and complex, and have a strong geographical nature, the economy, ecological environment and other fields are included in its design objectives, and these fields are related to each other.

2.2 Construction of the Indicator System

(1) Determine the evaluation factors. The eco-building indicator system constructed in this paper belongs to a two-level and three-level indicator system, with the first level of judgement being the judgement of the indicator level on the criterion level, and the second level of judgement being the judgement of the criterion level on the target level, so this evaluation model is a two-level and three-level system. U={A1, A2, A3, A4,A5,A6}={Green Building: Land and Material Conservation, Indoor Environment, Water and Energy Conservation, Operation and Management},The secondary indicator level factors areA1 = {B1, B2, B3, B4, B5}, A2 = {B6, B7, B8}, A3 = {B9, B10, B11}, A4 = {B12, B13, B14}, A5 = {B15, B16, B17}, and A6 = {B18, B19, B20}.

(2) Evaluation grade. According to China's Green Building Evaluation Standard, the eco-buildings in this paper are divided into three grades according to the standard scores: when the standard score is less than or equal to 60 points, it is rated as one star; when the standard score is between 60 and 85 points, it is rated as two stars; when the standard score is between 85 and 100 points, it is rated as three stars.

(3) The weight vector of evaluation indicators. In this paper, ρis used to represent the level of indicators, and the judgement matrix is constructed with the help of triangular fuzzy number, and this is used to compare the importance of each factor[6]. As the data given by the experts do not need to be particularly accurate, it is only necessary to compare the relative importance of the indicators according to the criteria, quantify them, and then arrive at the upper limit, middle value and lower bound value of the judgement, which are the weight vectors of the evaluation indicators[7].

In this paper, ρis used to indicate the level of the indicator, and the judgement matrix is constructed with the help of triangular fuzzy number, which is used to compare the importance of each factor. Since the data given by the experts do not need to be particularly accurate, it is only necessary to compare the relative importance of the indicators according to the criteria, quantify them, and then derive the upper limit, intermediate value and lower bound value of the judgement, which are the values of $u_{i,j}^{k}$, $m_{i,j}^{k}$, $l_{i,j}^{k}$,If there are k experts to provide the data, the ratio of the combined importance of the indicators i and j, i.e., the fuzzy number of the delta is

$$M_{i,j}^{\rho} = \frac{1}{K} * \sum_{k=1}^{k} b_{i,j}^{k}$$
$$= \left(l_{i,j}^{p}, m_{i,j}^{p}, u_{i,j}^{p}\right)\left(\sum_{k=1}^{k} b_{i,j}^{k}\right)$$
$$=\left(\sum_{i,j}^{k}\left(\sum_{k=1}^{k} m_{i,j}^{k}, \sum_{k=1}^{k} u_{i,j}^{k}\right)\right) \quad (1)$$

The combined importance value of indicator i at level ρ relative to all other indicators at this level is denoted as:

$$S_{i}^{p} = \sum_{j=1}^{n} M_{i,j}^{p} * \left[\sum_{i=1}^{m}\sum_{j=1}^{n} M_{i,j}^{p}\right]^{-1} \quad (2)$$
$$\sum_{j=1}^{n} M_{i,j}^{p} = \left(\sum_{j=1}^{n} l_{i,j}^{p}, \sum_{j=1}^{n} m_{i,j}^{p}, \sum_{j=1}^{n} u_{i,j}^{p}\right)$$

Among them:

$$\left[\sum_{i=1}^{m}\sum_{j=1}^{n} M_{i,j}^{p}\right]^{-1}$$
$$= \left[\frac{1}{\sum_{i=1}^{m}\sum_{j=1}^{n} u_{i,j}}, \frac{1}{\sum_{i=1}^{m}\sum_{j=1}^{n} m_{i,j}}, \frac{1}{\sum_{i=1}^{m}\sum_{j=1}^{n} l_{i,j}}\right]$$

that $S_{i}^{p} = (l_{1}^{p}、m_{1}^{p}、u_{1}^{p}、)$, $S_{i}^{p} = (l_{2}^{p}、m_{2}^{p}、u_{2}^{p}、)$ are two triangular fuzzy numbers V ($S_{2}^{\rho} \geq S_{1}^{\rho}$)denote a triangular blur ($S_{2}^{\rho} \geq S_{1}^{\rho}$)The extent to which this is possible，then

$$V\left(S_{2}^{p} \geq S_{1}^{p}\right) = \begin{cases} \frac{l_{1}^{p} - u_{2}^{p}}{(m_{2}^{p} - u_{2}^{p}) - (m_{1}^{p} - l_{1}^{p})} \\ 1 \end{cases} \quad (3)$$
$$W_{j}^{\prime p} = \min V(S_{i}^{p} \geq S_{j}^{p}), j = 1,2,3 \cdots, j \neq i$$

Normalisation Obtains a weight vector of p-level evaluation indicators:

$$W^{p} = \{w_{1}^{p}, w_{2}^{p}, w_{3}^{p}, \cdots\cdots w_{n}^{p}\}$$
$$\left[\frac{w_{1}^{\prime p}}{\sum_{i=1}^{n} w_{i}^{\prime p}}, \frac{w_{2}^{\prime p}}{\sum_{i=1}^{n} w_{i}^{\prime p}}, \frac{w_{3}^{\prime p}}{\sum_{i=1}^{n} w_{i}^{\prime p}}, \frac{w_{4}^{\prime p}}{\sum_{i=1}^{n} w_{i}^{\prime p}}\right] \quad (4)$$

(4) Construct a comprehensive judgement model. According to the weight vector of each secondary indicator W_{ai}^{2} and its single-factor R_{ai} matrix for the first-level fuzzy comprehensive evaluation, the affiliation degree of each evaluation level can be obtained:

$$B_{i} = W_{ci}^{2} \times R_{ai} = (b_{i1}, b_{i2}, b_{i3}) \quad (5)$$

This results in a fuzzy affiliation matrix for the first level indicators:

$$R = (B_{1}^{T},\ B_{2}^{T},\ \cdots B_{n}^{T}) \quad (6)$$

Based on W' and R, a second-level fuzzy integrated evaluation was performed:

$B = W' \times R = (b1, b2, b3)$. (7)

Finally, according to the principle of maximum affiliation, the final judgement is given that if

$b_{ja} = \max(b_i)(1 \leq j \leq 3)$ (8)

then the eco-buildings are classified as J0.

3 Engineering Examples

May 4th - Square Station is located at the intersection of Hong Kong Middle Road and Shandong Road in Shinan District, Qingdao City, Shandong Province, China. It is an interchange station between Qingdao Metro Line 2 and Qingdao Metro Line 3[8]. The length of the main body of the station is 276.2 metres, the width is 43.4 metres, the width of the platform is 14 metres, and the effective platform length is 120 metres. The underground main building area is 24872.96 square metres, as of July 2023, the station has a total of 7 entrances and exits.The first basement level is the station hall level, with the main equipment management room area at the west end, the necessary equipment rooms and commercial rooms at the east end, a public area in the middle of the station hall, a pay zone in the middle of the public area, non-pay zones at both ends, and entry and exit gates and a fixed fence separating the two zones, with a ticketing office near the exit gates on the separating strip, and sufficient space for passengers to gather and disperse within the non-pay zone[9].

According to the experts' scoring of the indicators in the building, the relative importance between the indicators is collated, and the fuzzy judgement matrix of the first-level indicators is obtained by combining the numerical metric scale. The importance of each level of indicators is calculated by equation (2), where the importance of A1 is

$s_1^1 = (8.12, 10.80, 13.1 \times \left(\frac{1}{51.86}, \frac{1}{38.12}, \frac{1}{30.13}\right)$

=(0.16，0.28，0.44)

And so on to find the importance of A2 = (0.11,0.21,0.33), Importance of A3 =(0.09,0.18,0.33), Importance of A4 =(0.10, 0.18, 0.31), Importance of A5 =(0.07, 0.13, 0.21), Importance of A6=(0.07,0.11, 0.20).

Calculated from equation (3), $S_i^p \geq S_j^p$ degree of possibility ($V(S_i^p \geq S_j^p)$ =0.708， Then the weight vector of A1 is found according to equation (4), and the final weight vector composed of A1 to A6 is.

$W^1 = \{0.293, 0.068, 0.223，0.083，0.186，0.149\}^T$

According to the experts' scores on each level 2 indicator, and the fuzzy affiliation matrix Rai corresponding to the 20 level 2 indicators calculated by Equation (6), the fuzzy comprehensive judgement of the first level is carried out, and the affiliation of level 1 indicator A1 for each evaluation level is obtained:

$B_1 = W'_{a1} \times R_{a1}$

$= (0.183, 0.275, 0.185, 0.275, 0.186) \begin{bmatrix} 0 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}$

$= (0.182, 0.382, 0.436)$

The affiliation vectors of A2 to A6 for each evaluation level can be obtained by analogy. degree vector. Combine the weights of the first-level indexes with the affiliation vectors of the first-level indexes to each evaluation level, and then make a comprehensive evaluation of the eco-buildings according to equations (6) and (7), Its affiliation B = W× R = (0.085, 0.053, 0.039).

Table 1 Combined importance and weights of tier-1 indicators

V(S i)≥S	S1	S2	S3	S4	S5	S6	Wi
S1	1	1	1	1	1	1	0.293
S2	1	1	1	1	1	0.736	0.068
S3	1	1	1	1	0.653	0.924	0.223
S4	1	1	1	1	0.6423	0.936	0.083
S5	1	1	0.294	0.582	0.693	0.683	0.186
S6	1	0.236	0.513	0.654	0.612	0.935	0.149

In the evaluation model constructed in the actual case, land saving and outdoor environment rank first among the first-level indicators, followed by indoor environment, energy saving and utilisation, and operation management, with the weights of these four factors adding up to 84.9%.

In the evaluation model constructed in the actual case, land saving and outdoor environment rank first in the first-level index, followed by indoor environment, energy saving and utilisation, and operation management.

The weights of these four factors add up to 84.9%, indicating that they occupy a dominant position in the evaluation of eco-buildings, which is also in line with people's understanding of eco-buildings, and thus verifies the correctness of the model.

Among the secondary indicators, peripheral air quality and daylighting, indoor air quality, energy efficiency of the main body of the building and optimal use of conventional energy systems, management measures and systems and their impact on the surrounding environment, water supply and drainage systems, green materials[10].

Indoor air quality, energy saving in the main body of the building and optimal use of conventional energy systems, management measures and systems, and impact on the surrounding environment, water supply and drainage systems, and green materials[11]. In order to continue upgrading buildings, we should focus on improving the indoor environment, energy saving and energy use, and operation and management, because their affiliation degree exceeds 0.5 (Table 2). It shows that they are the main reasons hindering the upgrading of building quality[12].

Table 2 Results of the composite level judgement for tier 1 indicators

Projects	Affiliation to levels			Level of judgement
	1.000	2.000	3.000	
A1 Land Saving and Outdoor Environment	0.182	0.382	0.436	3
A2 Material conservation and resource utilisation	0.000	0.436	0.564	3
A3 Indoor environmental quality utilisation	0.000	0.764	0.236	2
A4 Water conservation and water use	0.000	0.000	1.000	3
A5 Energy conservation and energy use	0.109	0.514	0.377	2
A6 Operations management (OM)	0.000	0.853	0.147	2
Eco-Building Class for Metro Stations	0.085	0.536	0.379	2

4 Conclusions and Perspective

In this paper, on the basis of the original ecological building evaluation system of metro stations, the hierarchical analysis method and the fuzzy comprehensive judgement principle are added to reconstruct the comprehensive evaluation model of metro stations' ecological buildings, which further improves the existing linear evaluation model[13].

The model can also be used to quickly develop ecological building indicators for metro stations according to geographical characteristics in the evaluation process. In the process of using the model, the weights need to be adjusted according to the actual situation in order to make the evaluation results more in line with the actual situation.

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