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Comprehensive evaluation and case study of urban underground space development under multiple constraints

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This paper presents a research on the evaluation and case analysis of urban underground space development under several constrains such as geological, technical and economic factors. To solve the problem of incomplete information, correlation and ambiguity in the multi-restrictive environment factors were comprehensively evaluated. First of all, six main factors which restrict the urban underground space sustainable development were selected; secondly, the degree of the restrictive factors and their frequency were discussed, the restrictive factors which occupied more than 95% were determined by expert advice, the evaluation index was quantified by the Likert scale, the evaluation index system of urban underground space sustainable development and utilization was constructed. Moreover, Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation Method (FCE) were used to construct the fuzzy comprehensive evaluation model of multi-level constraints, the weight vector for consistency check was calculated, and the fuzzy evaluation membership matrix was computed. Finally, Jiangbei District, Hechuan District and Qianjiang District in Chongqing City were chosen as representatives of urban function core district, city development district, and southeast ecological reserve district in Chongqing City. The urban underground space sustainable development in the chosen districts was analyzed by the multi-factors fuzzy comprehensive evaluation model, and the evaluation results were verified by multi-level grey assessment. The case study results showed that applying AHP and FCE method for multi-constraint factors comprehensive evaluation of urban underground space sustainable development has high viability and effectiveness for the beneficial exploration and comprehensive evaluation of multi-restrictive environment factors.

Key words: Urban underground space, Multi-constraints environments, Sustainable development, Index system, Fuzzy comprehensive evaluation

INTRODUCTION

Rational development of urban underground space can effectively alleviate the shortage of city land, and effectively deal with environmental pollution, ecological deterioration and urban traffic congestion problems [1], and contribute to the intensive use of urban land resource and urban sustainable development [2]. Compared with the exploitation of ocean space resource, universe space resource and so on, the development of underground space resource is more direct, economic and secure. Compared with the urban ground space resources, potential urban underground spaces for urban development are relatively large, which are the products of general area multiplied by the depth of development 40% [3]. As a "potential and abundant natural resource" [4] urban underground space has been widely used in transportation, warehousing, air defense, environmental protection, energy, housing, commerce, culture, entertainment, sports and other fields in the developed countries, for example, stone mined-out areas were used as tombs, churches, wine cellars, drains, etc in Paris in the 12th century [5]; the world's first underground railway was built in London, England, in 1863 [6], after that, the underground railways were promoted rapidly by New York, the United States, Tokyo, Japan and other international cities [7]. The stage of development of urban underground space can be divided in urban subway early utilization, the Second World war, the urban Renaissance, the oil crisis impact, environmental protection demands [8], and it is now moving in the sustainable development stage [9]. In recent years, China's urban underground space development also got rapid development [10], but the overall level is still in the primary, dot, shallow stage of development [11], such as urban underground space waste, unreasonable layout and resource development sequence confusion [12]; there are also a series of restrictive factors for sustainable development of urban underground space [13].

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EXPERIMENTAL

Research ideas

The research idea of this article is to establish the index system, which is the basis framework of comprehensive evaluation, and then establish a multi-restriction-factors fuzzy comprehensive evaluation model of sustainable development of urban underground space, to analyze and demonstrate the urban underground space sustainable development.

The coordinated development of resources, environment, economics and society is emphasized in urban sustainable development [41]. Urban underground space is the downward extension of urban space resource, and the urban underground space sustainable development should include but is not limited to these four aspects. Theoretically speaking, the development of urban underground space is almost infinite. But considering the feasibility, security, economics, sustainability of development of urban underground space, there are not only problems such as long construction period, large investment, complex technology, high risk, difficult in disaster relief etc., but also many unfavorable environments such as geotechnical stability, hydro-geological conditions [42], construction technology, economic level, environmental benefits [43].

Through investigation and analysis of the frequency statistics and control degree of the restrictive factors, the indices which have higher frequency or larger control degree were chosen to compose of the preselected evaluation indices set. Then the characteristics of the preselected indices were analyzed, according to the frequency and the degree of restriction. Finally, the fewer indices, which have the most important restrictive effects on the urban underground space sustainable development were chosen to compose the index system.

Therefore, four items of work were carried out in this paper as follows: Firstly, the main constraint environments which influence the urban underground space sustainable development were analyzed from the perspective of engineering geology, environment consciousness, regional economics, technical standards, laws and regulations, etc. Secondly, through consultations, statistics, analysis of expert opinions, the main constraint factors were classified and quantified to layer, the weight of each index was calculated by using software. Thirdly, the evaluation index system and fuzzy comprehensive evaluation model of multi-level constraint factors were established by using the fuzzy mathematics theory. Fourthly, by consulting experts, taking the administrative area of urban underground space as the evaluation unit, representative urban underground space administrative districts were chosen for empirical analysis, to verify the reliability and validity of the method.

Establishing a fuzzy comprehensive evaluation index system of sustainable development of urban underground space

Selection of evaluation index. Firstly, a preselected evaluation index needs to be set. The primary evaluation index system was divided into two levels, the fist level is criterion layer and the second level is index layer. In the criterion layer there are 5 first-level control indices, which contain engineering geology, environmental consciousness, regional economy, technical standards, laws and regulations. There are 4 second-level restriction indices belonging to engineering geology index, which include geological uncertainty, bad geological susceptibility, regional instability, rock and soil corrosivity, to reflect the restriction conditions of regional characteristics and geological availability on the development of urban underground space. There are 4 second-level restriction indices belonging to environmental consciousness index, which include ideas, knowledge level, environmental conditions. Connection systems reflect the constraints conditions of interactive impact on the environment of exploitation of urban underground space. There are 4 second-level restriction indices belonging to regional economy index, which include *per capita* GDP, project cost, input-output ratio, return on investment cycle, to reflect the restriction conditions of urban social economic conditions or comprehensive benefit of the underground project on the urban underground space sustainable development. There are 4 second-level indices belonging to technical standards index, which include standard specification, technical research, construction difficulty, safety risk, to reflect the restriction conditions of technology level and risk control ability on sustainable development of urban underground space; There are 4 second-level restriction indices belonging to laws and regulations index, which include management regulations, laws and regulations and management function, land use right, overall planning, to reflect the restriction conditions of the administrative ability and comprehensive evaluation ability, corresponding laws and regulations and public participation in the process of development of urban underground space.

Secondly, the pre-selected evaluation indices were screened out by using expert consultation method, which is confirmed through some expert opinions and scored the indices respectively. Expert opinion consultation table was designed in two parts: the first part was designed for asking experts' opinions on the evaluation index and experts can add, delete and adjust the pre-selected indices; the second part was designed for asking experts score the indices by using Likert scales, the score of each index was divided into five levels such as: very important, important, generally important, less important and not important and given 5, 4, 3, 2, 1 score. Average arithmetic score values were thought to represent expert opinions concentration, and the coefficient of variation was used to represent the opinion coordination degree. The less the coefficient of variation, the higher is the degree of coordinated expert opinion targets. The screening standard was set to when the arithmetic mean value is greater than 3.5 and the coefficient of variation is less than 0.25.

In order to obtain the basic data, 30 experts accepted the surveys of design, management, research, questionnaire, and who were from Chongqing Survey Institute, Chongqing city rail transit (Group) Co. Ltd., Chongqing Design Institute, Chongqing municipal engineering design and Research Co Ltd, Chongqing City Planning Bureau, Chongqing Jiao tong University and other 10 units engaged in design and construction of underground space resource in city. All experts agreed that the evaluation index system can be divided into criterion layer and index layer, and there was no objection to the criterion layer index's composition, but there were some adjustment advices on the composition of index layer by 11 experts. At the same time, experts scored all the first-level control indices of the criterion layer and second-level control indexes of the index layer separately.

Finally, statistical analysis was carried out on the data obtained from the expert opinion consultation table with the above method, the opinion concentration degree and the opinion coordination degree of each index were calculated, and finally 5 first-level indices concerning regional economy and 20 second-level indices concerning *per capita* GDP were set to compose the indices set for decision-making system of the urban underground space sustainable development and utilization, $U=\{U_1, U_2,…, U_5\}=\{U_{11}, U_{12},…, U_{54}\}$, as shown in Table 1. The 20 specific indices were the most important and the most critical factors, accounting for more than 95% of all factors, and were enough to reflect the restriction condition of the urban underground space sustainable development and utilization.

Calculation of decision weight index

The weight coefficient of each evaluation index was determined through analytic hierarchy process (AHP) method, which can make the index and its

Table 1. Evaluation index system and weights of the indices for evaluation of the urban underground space sustainable development and utilization

Criterion layer	Weight of criterion layer(A_i)	Index layer	Weight of index layer(A_{ij})
Regional economy (*U_1*)	0.2719	Per capita GDP (U_{11})	0.1709
		Engineering cost (U_{12})	0.4227
		Input-output ratio (U_{13})	0.2165
		Investment return period (U_{14})	0.1899
Technical standards (*U_2*)	0.1974	Standard specification(U_{21})	0.2220
		Technology research (U_{22})	0.1306
		Construction difficulty(U_{23})	0.2774
		Safety risk (U_{24})	0.3700
Laws and regulations (*U_3*)	0.1720	Management regulations (U_{31})	0.2239
		Management functions (U_{32})	0.0829
		Land use rights (U_{33})	0.3733
		Overall planning (U_{34})	0.3199
Engineering geology (*U_4*)	0.2290	Geological uncertainty (U_{41})	0.1479
		Bad geological susceptibility (U_{42})	0.1740
		Regional instability (U_{43})	0.6429
		Rock and soil corrosion (U_{44})	0.0352
Environmental awareness (*U_5*)	0.1297	Ideas (U_{51})	0.2460
		Understanding level (U_{52})	0.0869
		Environmental status (U_{53})	0.3000
		Connection system (U_{54})	0.3671

Note: this table is comprehensive expert advice, which is analyzed, sorted and calculated.

weight more reasonable, more practical and easily quantitatively represented. 1–9 scaling law was used by the experts to compare with the relative importance of the two-two factors of evaluation index of the multiple constraint factors of development of urban underground space. In view of different views on the relative importance of evaluation indices by the experts, the final index calibration value can be obtained by twice feedback evaluation, then the judgment matrix of each hierarchy can be constructed, and weight vector calculation and consistency check were applied by calculation software.

Here, the evaluation index in the criterion layer was taken as an example to illustrate the weight computational process. The judgment matrix of the evaluation index in the criterion layer is listed in Table 2. The maximum feature vector value can be obtained λ_{max}=5.003, when the judgment matrix is input to the software, the corresponding eigenvector is: A=(0.2719, 0.1974, 0.1720, 0.2290, 0.1297), the coincidence index is:

$$CI = \frac{\lambda_{\max} - n}{n-1} = (5.0030-5)/(5-1)=0.00075 \quad (1)$$

the mean random consistency index is:

$$CR = \frac{CI}{RI} = 0.00075/1.12=0.000625 < 0.1 \quad (2)$$

RI is the mean random consistency index of the judgment matrix, which can be obtained from Table 3. It can be seen that the judgment of the weight value of the criterion layer is reliable. Otherwise, the values in the judge matrix need to be adjusted. Thus, the criterion layer evaluation index weight coefficient A=(0.2719, 0.1974, 0.1720, 0.2290, 0.1297).

The judgment matrix of the evaluation index in the second-level index layer is listed in Table 4. Meanwhile, the weight coefficients A_{ij} of each evaluation index can be obtained, the evaluation index weight coefficient in the second-level index layer A_{1i} = (0.1709, 0.4227, 0.2165, 0.1899), A_{2i} = (0.2220, 0.1306, 0.2775, 0.3700), A_{3i} = (0.2239, 0.0829, 0.3732, 0.3199), A_{4i} = (0.1479, 0.1740, 0.6429, 0.0352), A_{5i} = (0.2460, 0.0869, 0.3000, 0.3671) and can be passed through the consistency test, the results are shown in Table 1.

Multi-level fuzzy evaluation model of sustainable development for urban underground space

Five indices in the first-level criterion layer and 20 indices in the second-level index layer of sustainable development of urban underground space affect and restrict each other, and show a nonlinear relationship, which makes the prediction and evaluation fuzzy and subjective. Considering that it is difficult to put all the restricting factors of sustainable development of urban underground space into the evaluation index system, and based on the limited cognitive level and decision information, using fuzzy comprehensive evaluation method (FCE) is a way to solve these problems. It can be well combined with the qualitative evaluation and quantitative evaluation, and be able to better control man-made interference factors, and the decision result is as close as possible and can reflect the real situation. According to the established evaluation index system, using the theory of fuzzy mathematics, the main steps are to establish the multi-level fuzzy comprehensive evaluation model of sustainable development of urban underground space as follows:

First step: the given factors set U={U_1, U_2,…, U_n} is divided into subset S in accordance with certain attributes:

$$U_i=\{U_{i1},U_{i2},\cdots,U_{in}\} i=1,2,3\cdots,S, \quad (3)$$

The conditions as follows:

(a) $n_1+n_2+\cdots+n_s=n$;

(b) $U_1 \cup U_2 \cup \cdots \cup U_s=U$;

(c) $U_i \cap U_j=\Phi, i\neq j$.

Table 2. The judge matrix of the evaluation index in the criterion layer

Index	U_1	U_2	U_3	U_4	U_5
U_1	1	9/7	9/6	9/8	9/4
U_2	7/9	1	9/8	8/9	9/6
U_3	6/9	8/9	1	7/9	9/7
U_4	8/9	9/8	9/7	1	9/5
U_5	4/9	6/9	7/9	5/9	1

Table 3. Mean random consistency index RI

Order of matrix (n)	1	2	3	4	5	6	7	8	9	10
Mean random consistency index (RI)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Table 4. Judge matrix of the evaluation index in the second-level index layer

Index	U_{11}	U_{12}	U_{13}	U_{14}
U_{11}	1	0.4	0.75	0.9
U_{12}	1/0.4	1	0.75/0.4	0.9/0.4
U_{13}	1/0.75	0.4/0.75	1	0.9/0.75
U_{14}	1/0.9	0.4/0.9	0.75/0.9	1

Index	U_{21}	U_{22}	U_{23}	U_{24}
U_{21}	1	1.7	0.8	0.6
U_{22}	1/1.7	1	0.8/1.7	0.6/1.7
U_{23}	1/0.8	1.7/0.8	1	0.6/0.8
U_{24}	1/0.6	1.7/0.6	0.8/0.6	1

Index	U_{31}	U_{32}	U_{33}	U_{34}
U_{31}	1	2.7	0.6	0.7
U_{32}	1/2.7	1	0.6/2.7	0.7/2.7
U_{33}	1/0.6	2.7/0.6	1	0.7/0.6
U_{34}	1/0.7	2.7/0.7	0.6/0.7	1

Index	U_{41}	U_{42}	U_{43}	U_{44}
U_{41}	1	0.85	0.23	4.2
U_{42}	1/0.85	1	0.23/0.85	4.2/0.85
U_{43}	1/0.23	0.85/0.23	1	4.2/0.23
U_{44}	1/4.2	0.85/4.2	0.23/4.2	1

Index	U_{51}	U_{52}	U_{53}	U_{54}
U_{51}	1	2.83	0.82	0.67
U_{52}	1/2.83	1	0.82/2.83	0.67/2.83
U_{53}	1/0.82	2.83/0.82	1	0.67/0.82
U_{54}	1/0.67	2.83/0.67	0.82/0.67	1

Second step: for each factor set U_i, which is respectively to make comprehensive evaluation, and to let $V=\{V_1,V_2,\dots V_m\}$ is supposed to the evaluation set, the weight distribution of the various factors in U_i which is relation to V is: $A_i=\{a_{i1},a_{i2},\dots,a_{in}\}$, where $a_{i1}+a_{i2}+\dots+a_{in}=1$. R_i is the single factor evaluation matrix, then the one-level evaluation vector can be obtained:

$$B_i=A_i\cdot R_i=\{b_{i1},b_{i2},\cdots,b_{im}\},i=1,2,3,\cdots,S. \quad (4)$$

Third step: each U_i is regarded as a factor of U, $U=\{U_1, U_2,\dots, Us\}$, and then U is a set of factors, single factor evaluation matrix of U is:

$$R=\begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ B_S \end{bmatrix}=\begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1m} \\ b_{21} & b_{22} & \dots & b_{2m} \\ \dots & \dots & \dots & \dots \\ b_{S1} & b_{S2} & \dots & b_{Sm} \end{bmatrix} \quad (5)$$

where U_i is a portion of U, which reflects certain attributes, the weight distribution can be relying on the importance of them: $A=\{a_1,a_2,\dots a_s\}$,and then the second stage evaluation vector can be obtained:

$$B_i=A\cdot R=\{b_1,b_2,\cdots,b_m\} \quad (6)$$

Fourth step: the second-level evaluation vector is uneven, and the evaluation set is divided into 5 grades, with 5 points for each evaluation set. Each index is evaluated respectively: $V=(V_1,V_2,V_3,V_4,V_5)=(5,4,3,2,1)$ = (restriction influence is very large, restriction influence is larger, restriction influence is general, restriction influence is smaller, restriction influence is very small), then use the weighted average method to evaluate score and the sustainable exploitation of urban underground space.

Finally, according to the different evaluation results, the paper put forward strategies of the urban underground space sustainable development and utilization, and the multi-level gray evaluation method was applied to evaluation the results.

Case study

Chongqing city is the largest area resource of municipality directly under the central government of China. There are five functional areas of strategic deployment in Chongqing city’s space utilization from the perspective of sustainable development of urban space resource, based on the resources and environment bearing capacity, existing development density and development potential factors. The overall positioning of the city space resource development direction, development timing and strength of the overall positioning of the different parts has been put forward. Therefore, taking administrative district as basic assessment unit,3 administrative districts of Jiangbei, Hechuan, Qianjiang in Chongqing City has been selected as representative districts, and fuzzy comprehensive evaluation on the multiple constraint factors of sustainable development of urban underground space of Jiangbei District, Hechuan District, Qianjiang District has being done, respectively.

Calculation of the evaluation membership matrix

Experts are invited respectively to score the evaluation index of the multiple constraint factors of sustainable development of urban underground space of Jiangbei District, Hechuan District, Qianjiang District, then, the evaluation matrix of the multiple constraint factors of sustainable development of urban underground space of Jiangbei District, Hechuan District, Qianjiang District are made up.

Here, Hechuan District is taken as an example, firstly the evaluation matrix of the multiple constraint factors of sustainable development of urban underground space of Hechuan District is structured, and then the fuzzy evaluation membership matrix R_1, R_2, R_3, R_4 and R_5 are calculated.

$$R_1 = \frac{1}{30} \times \begin{bmatrix} 6 & 12 & 11 & 8 & 3 \\ 11 & 10 & 6 & 7 & 6 \\ 8 & 9 & 9 & 7 & 7 \\ 7 & 10 & 9 & 9 & 5 \end{bmatrix} \quad R_2 = \frac{1}{30} \times \begin{bmatrix} 7 & 6 & 8 & 10 & 9 \\ 4 & 7 & 6 & 10 & 13 \\ 8 & 7 & 8 & 9 & 8 \\ 10 & 9 & 7 & 7 & 7 \end{bmatrix}$$

$$R_3 = \frac{1}{30} \times \begin{bmatrix} 9 & 8 & 8 & 8 & 7 \\ 3 & 5 & 7 & 13 & 12 \\ 10 & 9 & 8 & 7 & 6 \\ 9 & 9 & 8 & 7 & 7 \end{bmatrix} \quad R_4 = \frac{1}{30} \times \begin{bmatrix} 6 & 7 & 8 & 9 & 10 \\ 7 & 8 & 9 & 10 & 6 \\ 12 & 10 & 9 & 5 & 4 \\ 3 & 5 & 6 & 15 & 11 \end{bmatrix}$$

$$R_5 = \frac{1}{30} \times \begin{bmatrix} 7 & 8 & 9 & 10 & 6 \\ 3 & 4 & 5 & 15 & 13 \\ 8 & 9 & 10 & 7 & 6 \\ 9 & 10 & 11 & 6 & 4 \end{bmatrix} \tag{7}$$

Fuzzy comprehensive evaluation

Using the weight of the evaluation index A_1 and fuzzy evaluation membership matrix R_1, B_1 was used by the software:

$$B_1=A_1 \wedge R_1=(0.2164,0.2508,0.1999,0.1870,0.1460) \tag{8}$$

Simultaneously, B2, B3, B4 and B5 can be obtained:

$$B2=A2 \wedge R2=(0.1999,0.1879,0.1842,0.2153,0.2126) \tag{9}$$

$$B3=A3 \wedge R3=(0.2219,0.2111,0.1979,0.1930,0.1760) \tag{10}$$

$$B4=A4 \wedge R4=(0.2481,0.2258,0.2187,0.1703,0.1370) \tag{11}$$

$$B5=A5 \wedge R5=(0.1922,0.2172,0.2422,0.2017,0.1469) \tag{12}$$

R and B can be obtained:

$$R = \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 0.2164 & 0.2508 & 0.1999 & 0.1870 & 0.1460 \\ 0.1999 & 0.1879 & 0.1842 & 0.2153 & 0.2126 \\ 0.2219 & 0.2111 & 0.1979 & 0.1930 & 0.1760 \\ 0.2481 & 0.2258 & 0.2187 & 0.1703 & 0.1370 \\ 0.1922 & 0.2172 & 0.2422 & 0.2017 & 0.1469 \end{bmatrix} \tag{13}$$

$$B=A \wedge R=(0.2182,0.2215,0.2062,0.1917,0.1624) \tag{14}$$

RESULTS AND DISCUSSION

Analysis of the evaluation results

The fuzzy vector is uneven, and each evaluation grade of the evaluation on the domain was assigned to $V_1=5,V_2=4,V_3=3,V_4=2,V_5=1$.The score of the multiple constraint factors of sustainable development of urban underground space of Hechuan District was obtained by using the weighted average method:

$$W1=(0.2182\times5+0.2215\times4+0.2062\times3+0.1917\times2+0.1624\times1)/(0.2182+0.2215+0.2062+0.1917+0.1624)=3.1414 \tag{15}$$

Similarly, the scores of the multiple constraint factors of sustainable development of urban underground space of Jiangbei District and Qianjiang District can be obtained. Respectively, $W_2=2.2817$, $W_3=4.4055$.

Then the fuzzy comprehensive evaluation scores of these three districts, Jiangbei District, Hechuan District and Qianjiang District, multi-constraint factors of urban underground space sustainable development were in the order: $W_2 < W_1 < W_3$.

According to the principle of maximum membership degree and the comparative analysis of the above fuzzy comprehensive evaluation, conclusions can be drawn about the Jiangbei District, Hechuan District and Qianjiang District of sustainable development of urban underground space constraints decision: because the regional economy of Jiangbei District is better and the engineering geological conditions of Jiangbei District are more stable, the influence on the multiple constraint factors of urban underground space sustainable development of Jiangbei District is between influence normal and influence smaller, and closer to influence smaller, the development of urban underground space of the Jiangbei District is in a strong sustainable stage and can be vigorously promoted.

Because the regional economy of Hechuan District is average and the engineering geological conditions of Hechuan District are suitable, etc, the influence on the multi-constraint factors of urban underground space sustainable development of Hechuan District is between influence general and restriction influence larger, closer to influence general, the development of urban underground space of the Hechuan District is in the basic stage of sustainabilitye and can be gradually developed.

Because the regional economy of Qianjiang District is relatively poor and the engineering geological conditions of Qianjiang District are more complex, the influence on the multiple constraint factors of urban underground space sustainable development of Qianjiang District is between influence very large and influence larger, but closer to influence larger, the development of urban underground space of the Qianjiang District is in a weak sustainable stage and can be gradually developed with cautions.

Validation of evaluation results

In order to verify the reliability of the multiple constraint factors for comprehensive evaluation of sustainable development of urban underground space based on AHP and FCE, the multiple level grey evaluation method was used to re-evaluate and the results were used as a comparison. The experts were asked to evaluate and sort on the multiple constraint factors of sustainable development of urban underground space of Jiangbei District, Hechuan District and Qianjiang District. The conclusions from the multiple level grey evaluation method were consistent with the results of the multiple constraint factors comprehensive evaluation. This shows that the multiple constraint factors comprehensive evaluation method of sustainable development of urban underground space has certain reliability and validity, and it can be in line with the actual situation of sustainable development of urban underground space, and achieve the expected goals.

CONCLUSIONS

The multiple constraint factors on the urban underground space sustainable development were comprehensively evaluated. It would be inconsistent with the real situation if the factors were considered separately from the effects of various restrictive factors neglecting the correlation between them. Simultaneously, it is difficult to take all the constraint factors which affect urban underground space sustainable development into the evaluation index system, and there are some ambiguities in the comprehensive evaluation information. AHP and FCE were used in this paper to construct the evaluation index system, which consists of 5 one-level criterion level indices and 20 two-level indices for urban underground space sustainable development, and the comprehensive evaluation model of urban underground space sustainable development was constructed based on AHP and FCE.

Case evaluation results showed that the comprehensive evaluation model of urban underground space sustainable development based on AHP and FCE can contribute to solve fuzziness and uncertainty problems of the evaluation process, whose comprehensive evaluation and the corresponding evaluation index system are feasible, credible, and it may be a new way which is beneficial for scientific and standardized comprehensive evaluation of urban underground space sustainable development and provides a reference for other fields.

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