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Fuzzy comprehensive evaluation of urban regeneration decision-making based on entropy weight method: Case study of yuzhong peninsula, China

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Abstract. Urban regeneration decision-making is a complicated system, which requires that stakeholder interests balance in aspects of the economy, society and environment. It is necessary to identify the key factors affecting urban regeneration and then construct an urban regeneration decision-making evaluation system to provide a basis for objective and comprehensive judgment for urban regeneration decision-making. Through constructing a fuzzy comprehensive evaluation model based on the entropy weight method, this paper attempts to provide a scientific evaluation method for the suitability of urban regeneration. An urban regeneration scheduling method by sorting the appropriate degree of the update of different areas in the large region, is proposed to achieve urban regeneration implementation in the sequence of time and space optimization.

Keywords: Urban regeneration decision-making, stakeholder, fuzzy comprehensive evaluation, entropy weight method

1. Introduction

Urban sprawl and urban regeneration (UR) are two important issues of urban development. A shortage of land resources leaves urban sprawl seriously limited, leading UR to become the primary direction of sustainable urban development. In addition, many universal problems are caused in old districts [4], along with the adjustment of industrial structure, and the rise of the service economy and technology [7]. A large number of redevelopment projects are under construction in order to revive dilapidated districts and buildings around the world [5, 10].

As a complex systematic process, UR is intended to focus not only on external building demolition and economic construction but also take into account cultural valuation and the potentiality of future development [9, 24, 23], in order to revive decay through the interaction of the physical, economic and social aspects [2].

Many foreign scholars [6, 8, 10, 18] have conducted research on success factors based on the concept of sustainable development. They generally consider that sustainable UR requires the government to maintain macro-control measures through urban planning and land use regulation [10, 21, 22], and to supply policy support and supervision to the investment behavior of developers [1]. Alastair Adair (2002), Ingrid Nappi-Choulet (2005), etc., reported that developers or investors for decision-making primarily make judgments based on the profitability of the investment [2, 13]. With the effective participation of the government and developers, the government must enhance the community's decision-making role through guidance

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and the delegation of authorization to community residents. It is also conducive to safeguard the rights and interests of the community [19].

Chinese scholars have studied process analysis and experiences from American and European decision-making modes, and have explored the successful foreign modes combined with the current domestic situation [11, 16, 28]. They sum up the problems existing in China, which include decision-making imbalance resulting in the uneven distribution of benefits and one-sided decision-making resulting in disorderly updating. Domestic scholars [26, 25] have attempted to construct the system based on interest, drive and operation mechanism, considering the driving role of external and internal forces in aspects of physical condition, economy, policy and culture. Making full use of the dynamic mechanism of various stakeholders is necessary to realize a diversified decision-making body and a comprehensive and systematic decision-making process.

Although UR is common in practice and theoretical research, the decision-making evaluation is still in the subjective judgment stage; unified evaluation criteria have yet to be identified. Therefore, it is of great significance to realize the validity of UR decision-making and implementation that constructs a quantitative comprehensive evaluation model through scientific statistical methods.

2. Methodology

On the basis of previous qualitative studies, quantitative analysis is conducted through fuzzy comprehensive evaluation (FCE) based on the entropy weight method. The literature review, questionnaire method, and the expert evaluation method were used to access the data and information. Then factor analysis, entropy weight method and FCE were implemented to deal with the collected data and information. Figure 1 depicts the implementation procedure, with three phases.

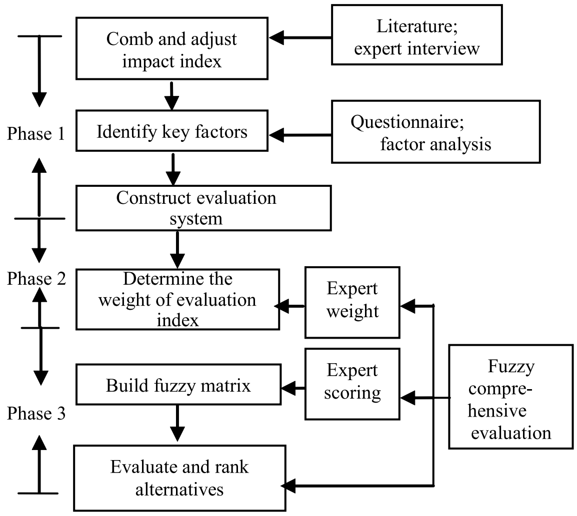

Fig. 1. The proposed integrated model.

2.1. *Key influence factor identification and the evaluation system construction of urban regeneration decision-making*

A variety of previous studies related to UR decision-making have supplied many reports to comb influence factor analysis. Appropriate deletion and adjustment can then be made when analyzing the current situation of Chinese UR. Ten excellent UR experts were invited to discuss and revise the arrangement results in order to increase the profesionalism of the research.

An influence index was designed for questionnaire design and designated as I_i $(i = 1, 2, \ldots, n)$ after the literature review and expert interviews. The questionnaire is designed in the form of the Likert Scale (1–5 represents the degree of influence on UR decision-making, from weak to strong) to survey m number of UR stakeholders. The key influence index (KII) I'_i $(i = 1, 2, \ldots, n')$ was then extracted from surveyed results by employing factor analysis with SPSS statistics software. The KII I'_i was then categorized into key influence factors to construct a UR decision-making evaluation system after correlation analysis to support quantitative FCE.

2.2. *Comprehensive weight of urban regeneration decision-making evaluation index*

Entropy technology can use the output entropy of each factor to determine its weight coefficient. Two steps are required to achieve the objective empowerment of the evaluation index. First, the entropy weight of each KII must be calculated. Then, use average calculating method to achieve comprehensive weight of each evaluation index, combined with classification of key influence factors.

A matrix is constructed based on questionnaire data. For KII I', if the j questionnaire respondent provided the judgment $I'_{i,j}$ regarding the degree of influence of UR decision-making on KII i, the influence degree matrix judged by all the questionnaire respondents on KII is $I'_{i,j}$. The matrix $I'_{i,j}$ is the conclusion of the fuzzy decision-making on KII by m decision-makers, representing the value of each decision-maker for each evaluation index [12].

Equations (1), (2) and (3) are the calculation formulas of entropy weight method. Define H_i as in Equations (1) and (2) and W_i i as in Equation (3). H_i is the entropy of KII I; W_i is the entropy weight of KII i that is equal to the KII weight coefficient in the UR decision-making evaluation. Then, the average weight of each index is calculated for key factors, representing the comprehensive weight of the evaluation index.

$$H_i = -K \sum_{i=1}^{n'} f_{i,j} \ln f_{i,j} \tag{1}$$

$$f_{i,j} = \frac{I'_{i,j}}{\sum_{j=1}^{m} I'_{i,j}},\ K = \frac{1}{\mathrm{lnm}} \tag{2}$$

$$W_i = \frac{1 - H_i}{n' - \sum_{i=1}^{n'} H_i}\ (i = 1, 2, ..., m) \tag{3}$$

2.3. Fuzzy comprehensive evaluation of urban regeneration decision-making

UR decision-making is a complicated system, affected by many factors, many of which cannot be quantified. In the comprehensive evaluation, FCE is used for quantitative treatment [17]. FCE is a method of comprehensive evaluation based on fuzzy mathematics. The principle of fuzzy relationship synthesis is applied to quantify the factors that are difficult to define and quantify.

The FCE method uses fuzzy transformation and weighted average principle to achieve comprehensive evaluation, considering the various factors of the multi-objectives and multi-layers related to the evaluation objects. It is the evaluation process of values, sorting and weighting for the evaluation index according to the particular case and targets of the evaluation objects.

The procedures for executing the method are as follows [12, 14, 15, 17, 24, 29]:

Step 1. Establish the factor set $F = \{F_1, F_2, \cdots, F''_n\}$ according to the evaluation system. F''_n is the key influence factor obtained by factor analysis;

Step 2. Determine the comment hierarchy $v = \{v_1, v_2, \cdots, v_p\}$ in accordance with the actual situation of decision-making selection, of the appropriate collection and refinement degree. The v_p is the state judgment to the evaluation factors by evaluators. The evaluation level must be quantified in order to obtain the quantitative index.

Step 3. Calculate the weight vector of the evaluation index $W = \{W_1, W_2, \cdots, W_{n''}\}$. The element W_i in the weight vector W is the membership degree of F_i to the fuzzy vector. The entropy weight method was chosen to determine the relative order of importance among the evaluation indicators. Determine the weights accordingly, and normalize before synthesis.

Step 4. Prepare a questionnaire to investigate the relationships among the index items. A "t" number of evaluators evaluate the factor set $F = \{F_1, F_2, \cdots, F''_n\}$ according to the evaluation set $v = \left\{v_1, v_2, \cdots, v_p\right\}$ and the quantitative index. All evaluators should express their views on each factor (e_{ij} represents one evaluator who chose the evaluation factor F_i in the v_j evaluation level, judging its current situation) to obtain a fuzzy map. The fuzzy maps of all factors form the fuzzy matrix R.

$$R = \begin{bmatrix} R|\ F_1 \\ R|\ F_2 \\ \cdots \\ R|\ F_{n''} \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1p} \\ r_{21} & r_{22} & \cdots & r_{2p} \\ \cdots & r_{ij} & \cdots & \cdots \\ r_{n''1} & r_{n''2} & \cdots & r_{n''p} \end{bmatrix}_{n''.p} \tag{4}$$

$$(i = 1, 2, ..., n''; j = 1, 2, ..., p)$$

The r_{ij} is the subordinate degree of factor F_i to grade evaluation V_j; $r_{ij} = x_{ij}/t$ x_{ij} represents numbers of e_{ij} that indicate who selected the evaluation of grade V_j for factor F_i. The number t represents the total number of decision makers.

Step 5. Synthesize fuzzy synthetic evaluation result vector B. Use the model of $M(\bullet, +)$ to synthesize the weight vector W and the fuzzy map matrix R.

$$W \circ R = (W_1, W_2, \cdots\cdots, W_{n''}) \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1p} \\ r_{21} & r_{22} & \cdots & r_{2p} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n''1} & r_{n''2} & \cdots & r_{n''p} \end{bmatrix}$$

$$= \left(b_1, b_2, \cdots\cdots, b_p\right) = B \tag{5}$$

Step 6. Analyze FCE result vector B. In order to reduce the loss of information, the weighted average method (Equation (6)) is used to evaluate the membership grades comprehensively. B' is the FCE result. The multiple objects can be ranked according to the evaluation results.

$$B' = \frac{\sum_{i=1}^{p} b_i v_i}{\sum_{i=1}^{p} b_i} \quad (6)$$

3. Key influence factor identification and evaluation system construction of urban regeneration decision-making

UR is the reasonable reallocation of urban land and population resources [16]. The goals of UR include the social, economic and cultural components of material updating, the function adjustment of space structure and the optimization of the humanistic environment [20]. Decision-making is conducted based on the goals of the UR. In order to determine the scheduling of UR, the key factors affecting UR decision-making must first be identified. Then, the UR decision-making evaluation system is constructed according to the correlation of the key factors.

3.1. Influence index identification and selection of urban regeneration decision-making based on literature review and expert interviews

Previous literature [1–3, 6, 13, 20, 24, 26, 27] indicate that different stakeholders award different amounts of attention to the influence factors. Domestic scholars generally pay more attention to the improvement of social public interests due to the public's lower position in UR. Housing demolition is a major category of influence factors for UR decision-making in China.

Ten excellent UR experts were invited to discuss the influence index identified by the literature review and the expert interview form. A total of 82 influence indices,of UR decision-making I_i ($i = 1,2,\ldots,82$) are selected by summarizing and analyzing the interview results.

3.2. Extraction and analysis of the key factors affecting urban regeneration decision-making based on questionnaire and factor analysis

3.2.1. Key influence factor extraction of urban regeneration decision-making

A questionnaire is designed with respondents' basic information and 82 influence indices in the form of the Likert Scale, randomly distributed to 250 stakeholders including governors, real estate developers/investors, experts/scholars and the public (a generalized concept containing relocation households and other residents) via email and street interception.

The data processing uses factor analysis with SPSS statistical software. A total of 45 KIIs $I'i$ ($i = 1,2,\ldots,45$), are extracted. Then, nine key influence factors are classified by content and internal relationships such as social welfare (F_1), economic and real estate development level (F_2), public establishment (F_3), demolition and resettlement compensation (F_4), infrastructure (F_5), ecological environment (F_6), policy and planning (F_7), construction status (F_8), and investment behavior of developers/investors (F_9). These incorporate the main goal of UR in the aspects of society, economy, substance, ecological environment, policy, demolition and resettlement, and investment, which constitute the evaluation system of UR decision-making.

3.2.2. Key influence factor analysis of urban regeneration decision-making

Effective UR decision-making requires the common participation of stakeholders. Because the main stakeholders are involved in the survey, the influence factors can more comprehensively reflect stakeholders decision-making propositions. There are 30 indices reflecting the status of the regeneration area. They are primarily contained in the F_1, F_3, F_5, F_6, F_8 5 key influence factors, covering four aspects including ecological environment, building and facility, social welfare and commercial activity. This is fully reflected in that the status of building aging, infrastructure's backwardness and environmental pollution become the primary driving forces toward regeneration. The remaining 15 indices point to the interest demands of stakeholders in the UR process. The government is in pursuit of urban economic and social development; the developers/investors are in pursuit of high profits; the demolition households are in pursuit of reasonable compensation; other residents are in pursuit of more public resources.

4. Comprehensive weight of urban regeneration decision-making evaluation index

On the basis of the questionnaire data, the matrix $I'_{i,j}$ ($i = 1,2,\ldots,204$, $j = 1,2,\ldots,45$), $I'_{i,j} \in (1, 5)$) is constructed with the coordinates of the respondents and the above 45 key influence factors. $I'_{i,j} \in (1, 5)$) represents that the j questionnaire respondent provided the fuzzy evaluation for the degree of influence of UR decision-making on the KII i. Larger values indicate higher impact of that particular index. The matrix $I'_{i,j} \in (1, 5))$ is calculated by the entropy weight method according to Equations (1) through (3). Then the average weight of each key factor index is calculated for its contributeon to the overall evaluation index. The comprehensive weight of each key influence factor F_1, F_2, F_3, F_4, F_5, F_6, F_7, $F_{8,}$, and F_9 is 0.0256, 0.0173, 0.0255, 0.0192, 0.0241, 0.0274, 0.0159, 0.0218, and 0.0208, respectively.

5. Fuzzy comprehensive evaluation of urban regeneration decision-making

5.1. Analysis of regeneration area status of Yuzhong Peninsula, Chongqing

Yuzhong Peninsula was once the core economic zone in Chongqing due to its water transportation economic support. Howevver, most areas have gradually declined due to modern terminal economic decline and industrial structure adjustment. In recent years, Yuzhong Peninsula has gradually regenerated. Eight regenerating areas are selected: Dongshuimen area (A), Jiaochangkou-Shibati area (B), Qixinggang area (C), Xuetianwan area (D), Zhongshan Road area (E), Caiyuanba area (F), Eling-Fotuguan area (G), and Daping area (H). The locations of the eight areas are shown in Fig. 2. Using these areas as examples provides an FCE of UR decision-making. The regeneration suitability of each area is determined by evaluation results. Then, the arrangement of the regeneration sequence is determined.

5.2. Fuzzy comprehensive evaluation of the regeneration area

First, the factor set is identified and the evalution set is determined. According to the UR decision-making evaluation system, the factor set is established as $F = \{F_1, F_2, \ldots, F_9\} = \{$social welfare, economic and real estate development level, public establishment, demolition and resettlement compensation, infrastructure, ecological environment, policy and planning, construction status, investment behavior of developers/investors$\}$. According to the impact of the evaluation index on UR decision-making, the evaluation set is defined as $v = \{v_1, v_2, \ldots, v_5\} = \{$ possible for regeneration, suitable for regeneration, comparatively suitable for regeneration, quite suitable for regeneration, extremely suitable for regeneration$\}$. The quantitative index quantified by the evaluation set is obtained as $v = \{v_1, v_2, \ldots, v_5\} = \{1, 2, \ldots, 5\}$ within the Likert Scale.

Fig. 2. Regenerating instance area bitmap of Yuzhong Peninsula, Chongqing.

Second, a fuzzy matrix is constructed using expert evaluation results. An expert scoring method determines the membership degree of each evaluation index according to twenty excellent UR experts. An evaluation form was distributed to 20 experts for response. For one area, each of expert play tick in the corresponding blanks across each factor F_i (row) and evaluation level v_j (column) based on the area's current situation; a total of t forms are collected. The collected forms are summarized to count evaluation grade v_j for factor F_i. The results are then standardized. Finally, a matrix is constructed including all factors and evaluation levels. The fuzzy mapping matrices $(R_A - R_H)$ of the eight areas are then obtained.

Third, based on matrix $I'_{i,j}$ $(i = 1,2,\ldots,204, j = 1,2,\ldots,45)$ which represents the j questionnaire respondent to provide fuzzy evaluation regarding the influence degree on KII i, the entropy weights of the nine factors are calculated according to Equations (1) through (3). Results are then standardized to facilitate subsequent calculations. The comprehensive weight vector of each KII after standardization is $W = (0.1296, 0.0876, 0.1290, 0.0972, 0.1220, 0.1387, 0.0805, 0.1103, 0.1053)$.

Finally, the model of $M(\bullet, +)$ is used to synthesize the weight vector W and fuzzy mapping matrix R. The results are weighted averages to obtain the comprehensive evaluation results B' for each area according to Equations (5) and (6). The results are shown in Table 1 and Fig. 3.

The comprehensive evaluation result of area A is 4.43, indicating that the area is quite suitable for regeneration. There are many shanty towns; the declining status forces this area to regenerate inevitably with dilapidated houses, infrastructure's backwardness and a dirty environment. In addition to prospet planning and

Table 1
Comprehensive evaluation of regeneration areas of Yuzhong Peninsula, Chongqing

Area	Fuzzy evaluation results(B)					Comprehensive evaluation results (B')
	Possible for regeneration	Suitable for regeneration	Comparatively suitable for regeneration	Quite suitable for regeneration	Extremely suitable for regeneration	
A	0.03	0.06	0.14	0.47	0.29	3.92
B	0.07	0.02	0.05	0.12	0.74	4.43
C	0.04	0.13	0.39	0.34	0.10	3.34
D	0.07	0.26	0.32	0.30	0.05	2.98
E	0.07	0.21	0.52	0.20	0.01	2.86
F	0.06	0.20	0.22	0.29	0.09	3.17
G	0.15	0.21	0.19	0.36	0.10	3.07
H	0.12	0.38	0.18	0.26	0.07	2.79

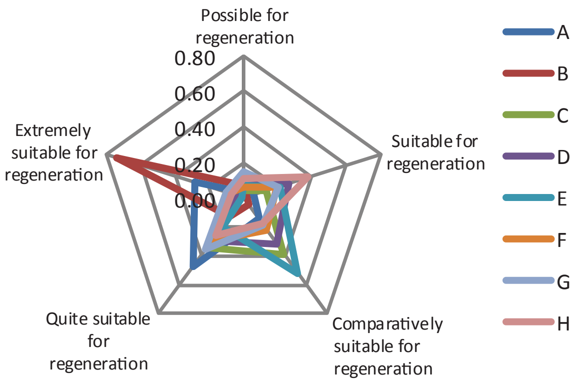

Fig. 3. Comprehensive evaluation of regeneration areas of Yuzhong Peninsula, Chongqing.

the soaring investment enthusiasm of developers, the UR implementation of this area will be conducive to realize the interest demands of stakeholders.

The evaluation results of areas *B*, *C*, *F* and *G* range from 3 to 4, indicating that they are comparatively suitable for regeneration. The facilities of area *B* are comparatively backwardness. However, the economic impetus of the Chaotianmen wholesale market cannot be ignored, leading to great development potential. The mature economy in area *C* attracts the attention of many investors and developers. However, it is difficult to redevelop with the high population density and large numbers of air raid shelters. Area F has convenient traffic and a developed economy. However, this area demonstrates serious environmental problems and the adverse influence of railway station and viaducts. This situation must be improved by regeneration. Area G becomes a primary choice for investors/developers to invest and residents to settle down owing to Eling-Fotuguan Park. Nevertheless, the slightly inconvenient traffic produces some impediment impact.

The evaluation results of areas *D*, *E* and *H* range from 2 to 3, indicating that they are comparatively suitable for regeneration. Area *D* lacks a strong regeneration demand with many large public facilities, coupled with financial support from the farm product market. However, this area is still suitable for regeneration due to the poor conditions of its buildings and environment. A portion of area *E* is subject to joint demolition, causing much dissatisfaction. However, there is still room for improvement in terms of the status of buildings, facilities and spatial pattern. Area *H* is the key support object of economic development and planning, located in the 6th commercial district. As an important way to realize development, this area's regeneration becomes the greatest implementable possibility.

5.3. Urban regeneration time sequence of Yuzhong Peninsula, Chongqing

There are large difference among status, demolition, planning and investment. It is impossible to understand the overall level of regeneration according to a single factor. UR decision-making is the comprehensive consideration result of all factors. Only by integrating the influence factors of UR decision-making using the FCE method can a valid evaluation result be obtained. The UR sorting suitability is as follows: area B > area A > area C > area F > area G > area D > area E > area H. This is the UR sequence arrangement of Yuzhong Peninsula.

6. Conclusion

UR decision-making is a complex process due to the various stakeholders and wide range of targets for updating. The key influence factors of UR decision-making are identified by intent acquirement for the main stakeholders in aspects of ecological environment, building and facility, social welfare, commercial activity. The different interest demands among stakeholders are that government is most interested in economic and social development of the city, real estate developers/investors pursue higher profits, the relocation households pursue reasonable compensation for housing, and the public pursues more public resources. The key factors combined constitute the UR decision-making evaluation system. The UR model of leading by the government and implementation by developers ignores the interest demands of demolition households and the public. Based on existing UR projects, there are different levels of contradiction between the government, developers and households, and the public, which proves that the imbalance in the UR decision-making system leads to failure in UR decision-making. Therefore, constructing a UR decision-making evaluation system is a beneficial method to achieve UR decision-making.

The financial pressure on the government, developers' profit preferences and other factors restrict the sufficient implementation of UR decision-making, which leads to an unmatched situation in the supply and demand of UR; the contradiction intensification among stakeholders, and the subsequent hindrance, is evident in the coordinated development of the city. Through analyzing the status of the UR decision-making influence factors in each area, the regeneration suitability is comprehensively evaluated. Then, the scheduling of the area regeneration is conducted Scientific methods are used to achieve objective evaluation in decision-making and implementation of UR and to determine the optimized implementation plan of UR in the sequence of time and space. This can achieve maximum satisfaction of regeneration needs under restricted conditions, and alleviate contradictions between stakeholders in the UR process. It is also conducive to promote the sustainable development of UR.

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