Fuzzy Comprehensive Evaluation System of Sustainable Development of Town House Construction Projects

Jun Chang, and Li Ma

Abstract—**Sustainable development of town house construction is one of the most important preconditions to ensure urban and even national sustainable development, yet research on evaluation system of town house construction projects is still very weak. This article reviews relative research achievements in this field, studies the implication of sustainable development of town house construction projects, and establishes a fuzzy comprehensive evaluation index system from resource, environment, economic, livable and social aspects, uses AHP and fuzzy mathematics methods to sets up a fuzzy comprehensive evaluation model, and illustrates the procedure of the evaluation model step by step.**

Keywords—**town house construction projects, civil engineering, sustainable development, comprehensive evaluation.**

I. Introduction

The town house construction not only has to request with the total programming of city mutually and consistently and together the total style of city, but also should to conform to sustainable development of the whole society. In 2009, United Nations Environmental Program-Sustainable Buildings and Construction Initiative (UNEP-SBCI) published a report stating that in most countries in the world, construction industry is the largest source of greenhouse gas emissions, it consumes more than one-third of the country's total energy. The situation in China is much worse. Along with the urbanization process continues to accelerate, a large quantity of housing construction projects have been complicated and greatly improve the quality of human life. Meanwhile many serious and even irreversible negative effects are brought to our living environment, natural resource and ecology.

No doubt in the process of town house construction projects' development, pursuit of the equilibrium of economic development, energy utilization with environmental and ecological protection has very important meanings. After 1990s, under influence of sustainable development strategy, environmental protection concepts, such as low-carbon economy, green building and sustainable energy, have sprung up. More and more scholars and experts devote in exploring the theory, method and practice of house construction projects' sustainable development. In 1998, Huovila and Koskela published the paper "Contribution of the principles of lean construction to meet the challenges of sustainable development" [1], described some examples of sustainable construction practices from different countries, suggested the challenges of sustainable development to be considered in the life cycle process of buildings, and discussed the potential and profitability of lean principles to promote sustainable construction from social, economic, ecological and cultural aspects. Accompanied by the scholars' research, the World Business Council for sustainable development (WBCSD), the Global Reporting Initiative (GRI) and the Organization for Economic Cooperation and Development (OECD) are all advocates of the method of evaluation indicators for sustainable development. Some international institutions began to study the sustainable evaluation methods and standards of housing construction projects, and passed a lot of empirical tests. The typical evaluation systems are LEED-leadership in energy and environmental design issued by U.S. Green Building Council, British BREEAM-Building Research Establishment Environmental Assessment Method and Japan CASBEE-comprehensive assessment system for building environmental efficiency.

Under the guidance of "Promote Construction by Means of Evaluation", based on previous study, we research town house construction projects' sustainable development from resource, environment, economic, livable and social aspects, use AHP and fuzzy mathematics methods to set up a fuzzy comprehensive evaluation model. The objective of this article is to contribute to promote the related research to a higher stage of development.

II. Implication Of Sustainable Development Of Town House Construction Projects

A. A Concept Which Should Be Observed From Life Cycle

Sustainable development refers to maintaining a certain development pace in a relatively infinite period of time, during which the quantity and quality of components of the whole system does not decay, but even increased, and form a mutually reinforcing virtuous cycle of development, hence it should be observed from life-cycle perspective[2], which is similar to production processes from extracting natural resources, stockpiling, manufacturing, marketing and consumption until

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Jun Chang is with School of Civil Engineering of Dalian University of Technology, Dalian, 116024 China

Li Ma is with School of Business of Dalian University of Technology, Panjin, 124221 China .

dumping and wastes recycling processing throughout the life cycle of the substance. The sustainable development of town house construction projects should cover the procedure from the site selection, planning, designing, building, completion acceptance, operation and maintenance until being pulled down and the disposal of construction wastes.

B. A Concept Which Dwells In Complex Engineering System

As a critical important component of human society's sustainable development system, which mainly consists of four major subsystems such as economy, resource, ecology and population, sustainable development of town house construction projects is also a complex engineering system, it is not only an entire process notion but also a full range idea; thus we should also consider it from all the aspects which may influence human society's sustainable development system. To be specific, the sustainable development of town house construction projects should reflect the idea of resource-saving, environment friendly, economic rational, livable and beneficial to social justice, so that to well meet the needs of contemporary people and helpful or at least not harmful for the ability of future generations to meet their needs of development.

C. A Concept Which Closely Connects To Green Building

Nowadays the sustainable development of house construction projects is more and more closely connected with the concepts of green and ecological building [3]. We can attribute the rapid growth of green building to human beings' increasing popular concept of sustainable development which makes an appeal for setting up awareness of caring for and loving the earth for the common future of human beings. Other factors, including higher energy prices, increased costs of building materials, and regulatory incentives, are also the pushing forces [4]. There is no single, widely accepted definition for green building, but research is revealing there are some common threads related to this concept, they are:

(1) Eliminate or reduce construct projects' environmental impacts on greenhouse gas emissions and natural resource consumption to the maximum extent;

(2) Improve health and wealth of the occupants and the whole society;

(3) Promote economic growth and economic returns.

Though more and more popular in the world both in theory and practice, green building continues to face with barriers, including the ability to deliver a green project at acceptable cost, this means that the sustainable development of town house construction projects also needs to concern financial indicators to make it cost-viable both to the project sponsors and clients.

III. Evaluation Index system Design Principle

We adopt the following principles set up the index system.

(1) Principles of comprehensiveness. This principle demands that all the factors, which may influence sustainable development of town house construction projects, must be taken into account.

(2) Principles of universality. To make the evaluation conclusion suitable for town house construction projects of a variety of fields with different features, and the evaluation results can be compared among them, the common laws of sustainability of construction projects and a general index system need to be summarized.

(3) Principles of rigorousness. This principle demands that the evaluation indexes involve a group of concepts in stratified structure and each has clear meanings distinguished from others and has moderate coherencies in connotation.

(4) Principles of briefness. There are many factors influence the sustainable development of town house construction projects, but controlling too many variables is nearly impossible, the follow-up question is which attributes are influential enough? Hence we should adopt the principle of briefness to grasp the main influencing factors and design the corresponding evaluation indexes to reflect their situations directly and efficiently.

(5) Principles of feasibleness. This principle demands that the data of evaluation indexes could be obtained through investigation, and the calculation technique is easily to be understood and applied.

IV. Design the Indexes and the hierarchical structure

According to the above principles, we consider the specific sustainable development demands on town house construction projects from resource, environment, livable, economic, and social aspects, and build the following multi-factor hierarchical index system as is shown in Table I.

V. EVALUATION Model OF Sustainable of town house Construction Projects

Owing to the ambiguous features of most of the indexes, which somewhat inevitably lead to inexact evaluation results, we choose fuzzy comprehensive evaluation method which combines Fuzzy set theory with Analytical hierarchy process (AHP). When people analyze complicated social phenomenon with little quantitative information, and when multi-goal, multi-criterion decisions need to be made, this method has been tested to be an effective way to fulfill the task. Owing to the large number of indexes, we adopt fuzzy comprehensive evaluation model of three stages [5]. The Evaluation model and its process are laid out as follows:

A. Set Up the Grade Sets of Indexes

We use symbol "*U*" to represent the object for evaluation, there are totally 27 indexes belong to different hierarchies and categories in the evaluation system listed in Table I, they form the factor set marked down as:

$$U = \{U_1, U_2, U_3, U_4, U_5\},$$

U_1, U_2, U_3, U_4, U_5 respectively has their own factors.

U_1={U_{11}, U_{12}, U_{13}, U_{14}, U_{15}, U_{16}, U_{17}},

U_2 = {U_{21}, U_{22}, U_{23}, U_{24}, U_{25}}...,

U_5 = {U_{51}, U_{52}, U_{53}, U_{54}, U_{55}, U_{56}}

TABLE I: SUSTAINABLE DEVELOPMENT OF TOWN HOUSE CONSTRUCTION PROJECTS EVALUATION INDEXES

Type	Index
Resource saving U_1	Construction land is efficiently used in construction (U_{11})
	Building materials are used thriftily in construction (U_{12})
	Reproducible and recyclable resources are sufficiently used in construction (U_{13})
	Electricity-saving facilities and technologies are sufficiently used in construction (U_{14})
	Water-saving facilities and technologies are sufficiently used in construction (U_{15})
	Resources can be well recycled after demolition according to well-prepared recycling plan (U_{16})
	Energy-saving system for living is well designed in the project to be delivered(U_{17})
Environmental protection U_2	Solid wastes discharge in construction (U_{21})
	Waste water discharge in construction (U_{22})
	Toxic emission in construction (U_{23})
	Noise pollution in construction (U_{24})
	Radioactive contamination in construction (U_{25})
Economic rationality U_3	FIRR(Financial Internal Rate of Return) of the town house construction project (U_{31})
	DIPP (dynamic investment pay-back period) of the town house construction project(U_{32})
	FNPV (Financial Net Present Value) of the town house construction project (U_{33})
	PTR (profit and tax investment ratio) of the town house construction project (U_{34})
	Operational and maintenance cost level during normal operation period (U_{35})
	Regeneration possibilities and corresponding cost level of the project (U_{36})
Livable condition U_4	Disaster prevention technology application degree of the town house construction project (U_{41})
	Refuse disposal system of the the town house construction project (U_{42})
	Public security environment of the the town house construction project (U_{43})
	Living facilities of the the town house construction project (U_{44})
	Transportation condition of the the town house construction project (U_{45})
	Education and Employment condition of the the town house construction project (U_{46})
Social justice U_5	Honesty and fairness principles in project operation and maintenance (U_{51})
	Beneficial to improve economic well-being standard of local residents (U_{52})
	Beneficial to improve local social credit (U_{53})
	Helpful for social stability and harmonious development (U_{54})
	Improve living environment quality of the surrounding area (U_{55})
	Respect all the project stakeholders' rights and interests (U_{56})

Suppose the evaluations of each single index U_{ij} (i =1, ⋯, 5, j =1，⋯，5) judged by the specialists can be ranked among five grades, then the grade set of index U_{ij} can be expressed as:

U_{ij} ={$u_{ij1}, u_{ij2}, \cdots, u_{ij5}$}

For example, the evaluations of the index "FIRR" (U_{31}) can be ranked among five grades as "far more than the standards"(u_{311}), "relatively more than the standards" (u_{312}), "passable" (u_{313}),"substandard" (u_{314}) and "far below the standards" (u_{215}); likewise the evaluations of the index "Construction land is efficiently used" (U_{11}) can be ranked among five grades as "perfectly efficient, "comparatively efficient", "passable", "inefficient" and "very inefficient", which are signed by $u_{111}, u_{112}, \cdots, u_{115}$ respectively. All grades of the evaluations should be ranked in order of identical influencing trend, i.e., either making the degree of sustainable development of town house construction projects from high to low or from low to high. Here we choose the first order. According to this principle, the grades of evaluations of the index "FNPV" (U_{41}) should be ranked as "very high", "comparably high", "about average", "comparably weak" and "weak", and expressed as $u_{411}, u_{412}, \cdots, u_{415}$ Space forbidding, here we won't give further detailed explanation of other indexes' grade set.

B. Set Up the Weight Sets of the Indexes

To what extent U_{ijk} (k=1, 2,…, 5) belongs to U_{ij}, is called degree of membership or grade weight of U_{ijk} to U_{ij}, and we use a_{ijk} to represent it. The value of a_{ijk} can be obtained by statistical processing of the specialists' opinions. First, organize a group of specialists of construction technology, environment engineering, project management, finance, law, etc., (generally a group of 20~50 specialists is appropriate, and the specialists should come from related fields with proper proportion), let the specialists investigate the practical circumstances of the factors for evaluation, and then collect their evaluation opinions. The value of a_{ijk} can be computed by the following equations:

$$a_{ijk} = X_k / X$$

Where, X_k equals the number of the specialists who regard the grade of index U_{ij} as u_{ijk}, and X equals the total number of the specialists who participate in the evaluation.

Therefore, the weight set of index U_{ij} can be expressed as:

A_{ij} =(a_{ij1} ， a_{ij2} ， … ， a_{ij5})

Where, the values of a_{ijk} has been normalized to make their sum equals 1, i.e., $\sum a_{ijk}=1$.

For fuzzy comprehensive evaluation of Multi- hierarchy, it still demands to compute each index's degree of membership to its correlated index of upper hierarchy; thereby we need to obtain the degree of membership of each index of each hierarchy to the whole system from upper to lower hierarchy. In our evaluation model built in this paper, the weight set of indexes of the uppermost hierarchy is: $A = (a_1, a_2, \cdots, a_5)$. The weight set of indexes of the second upper hierarchy is A_i = $(a_{i1}, a_{i2}, \cdots, a_{in})$, ($i$=1, 2,…, 6, n=5) .

Where the values of both $a_1, a_2, \cdots, a_5$ and $a_{i1}, a_{i2}, \cdots, a_{in}$ have also been normalized to make their respective sums equals 1.

We adopt Analytical Hierarchy Process (AHP) to compute the above weights. AHP mathematically processes human's thinking course and subjective judgment, simplifies system analysis and computing work. It is a great progress to introduce AHP to decision-making process. AHP includes three basic steps:

(1) To construct a multi-factor recursion model of hierarchical structure in the light of object to be achieved and the natures of the things to be researched.

(2) Based on this model, invite a number of specialists (better more than 20 from different fields of study) to judge the relative importance of each two indexes to their correlated indexes of upper hierarchy, and give quantitative expression, construct judgment matrix M .

(3) Find out the solution (characteristic root) of the equation:

$$M\omega = \lambda \max \omega$$

Where, the solution (characteristic vector) ω * is each index's overall sequenced weight to its certain correlated index of upper hierarchy. So the combined weights of the indexes of the lowest hierarchy to the whole system can be deduced. Thought consistency examination needs to be passed during this procedure.

C. Set Up the Judgment Set of the Whole System

We divide the judgment of sustainable development of town house construction project, which is the whole system's evaluation objective into five degrees of "low", "relatively low", "medium", "relatively high" and high". Thus the judgment set of the whole system is:

$$V = \{V_1, V_2, \ldots, V_5\}$$

Where, V_1 ， V_2 ， … ， V_5 represent the five different degrees of sustainable development of town house construction project from low to high.

D. Fuzzy Comprehensive Evaluation of the First Stage

The first stage fuzzy comprehensive evaluation is to evaluate the impact of the single index U_{ij} on the whole system. This impact can be determined by fuzzy comprehensive evaluation of all the grades of the single index U_{ij}. When evaluate this single index, no need to tell its specific condition, and no matter how ambiguous this index is, fuzzy comprehensive evaluation method can reflect its real impact on the whole system. Suppose we need to evaluate grade number k of index U_{ij}, i.e., U_{ijk}, and we use r_{ijkl} to represent the degree of membership of U_{ijk} to element number l of judgment set V, i.e., V_l (l=1, 2…, 5), the matrix of degree of membership of U_{ij} to V_l is:

R_{ij} =(r_{ijkl})$_{6\times5}$.

Then the evaluation matrix of first stage fuzzy comprehensive evaluation is: $B_{ij} = A_{ij} \odot R_{ij} = (b_{ij1}, \cdots, b_{ij5})$.

Vector ($b_{ij1}, \cdots, b_{ij5}$) represents degree of membership of U_{ij} to V_1, V_2,…, V_5. Here "⊙" is an arithmetic operator, it indicates multiplication of matrixes.

E. Fuzzy Comprehensive Evaluation of the Second Stage

The second stage fuzzy comprehensive evaluation evaluates all indexes U_{ij}. Obviously the single index judgment set of U_{ij} should be the first stage fuzzy comprehensive judgment set. We use r_{ijl} to represent the degree of membership of U_{ij} to V_l, the matrix of degree of membership of U_i to V_l is:

$R_i = (b_{ijl})_{5\times5} = (r_{ijl})_{5\times5}$.

Then the evaluation matrix of second stage fuzzy comprehensive evaluation is: $B_i = A_i \odot R_i = (b_{i1}, \cdots, b_{i5})$

Here vector $(b_{i1}, \cdots, b_{i5})$ represents degree of membership of U_i to V_1, V_2, …, V_5 .

F. Fuzzy Comprehensive Evaluation of the Third Stage

The third stage fuzzy comprehensive evaluation evaluates the whole system U . Obviously the single index judgment set of U_i should be the second stage fuzzy comprehensive judgment set. We use r_{il} to represent the degree of membership of U_i to V_l, the matrix of degree of membership of U to V_l is:

$$R = (b_{il})_{5\times5} = (r_{il})_{5\times5}$$

Then the evaluation matrix of third stage fuzzy comprehensive evaluation is: $B = A \odot R = (b_1, \cdots, b_5)$

Here, vector $(b_1, \cdots, b_5)$ represents degree of membership of U to V_1, V_2,…, V_5.

G. Process of the Evaluation Result

General methods of processing evaluation results contain methods of largest degree of membership, fuzzy distribution and weighted averages. Method of Largest degree of membership takes the corresponding result of Max $\{b_1, \cdots, b_5\}$ of B as the final evaluation result. It ignores the information provided by the other elements whose values is not the maximum one among $b_1, \cdots, b_5$, thus certainly will cause deviation. Therefore this method is only appropriate for gross description of the evaluation result. Method of fuzzy distribution takes the values of $b_1, \cdots, b_5$ as the different ratios to affirm corresponding grade of judgment set. This method is convenient for more all-around and deeper understanding of evaluation results. Method of weighted averages comprehensively considerate all element's contributions, to our opinion, it is the most appropriate method. In this paper we choose the method of weighted averages to process the evaluation results. Because the elements of judgment set is qualitative and need to be quantitative, we assign the elements' values as V_1 =1, V_2 =2, V_3 =3, V_4 =4, V_5 =5. Hence the evaluation result is**:**

$$V = B\,V^T = B(1,2,3,4,5)^T$$

Where V is a variable whose algebraic value lies between 1 ～ 5, it closer to 5 proves higher degree of sustainable development of the town house construction project, Closer to 1 , proves lower degree of sustainable development of the town house construction project.

VI. Conclusion

Construction Project evaluation theory has gone through 4 stages of development from its birth date: financial evaluation, economic evaluation, environmental impacts assessment and social assessment, i.e., from focusing on internal evaluation to paying attention to external benefits, and to taking meeting the basic needs of the people as the core of evaluation [6]. With environmentally sustainable house construction grow during the past years; its evaluation research also has been impelled. This paper establishes an evaluation index system from resource, environmental, economic, livable and social aspects, builds a fuzzy comprehensive evaluation model by using AHP and fuzzy mathematics methods. The authors have used this model in practice, gained satisfactory results and hence proved the feasibility of the evaluation model. Space forbidding, actual application examples are omitted. Combining this model with database technique can form a part of town house construction project decision support system, and produce a practical tool helping people to make scientific investment decision-making for realizing sustainable development goals of human beings.

Though our evaluation model has been tested by practical application, owing to limited application cases, it still has some inevitable defects and limitations, for example, firstly, the evaluation index system is incomplete and appeals for more carefully considered indexes; secondly, the evaluation method needs to be improved to make the evaluation result more accurate, we may consider the possibility of replacing AHP with ANP (the Analytic Network Process), on the basis of AHP, ANP considers the mutual effects of all factors or factors between adjacent layers, and concluded the mixed weights by using "super matrix" to comprehensively analyze the mutual-interacted and influenced relationship among factors. Some scholars argue that compared with AHP, the weights concluded by ANP tend to be more balanced and increased their feassibility and rationality, and consequently ANP is more suitable for evaluating sustainable development of enterprises [7] . Thirdly, different type of town house construction projects respectively has their special features, so there needs to be more targeted evaluation system to make pointed references for evaluation on their sustainable development.

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Doctor Jun Chang is a full professor in School of Civil Engineering of Dalian University of Technology. He got his doctor degree in technology from Wuhan University of Technology, China in 2003. He has published more than 150 papers in academic journals, takes charge in over 30 research projects of national and provincial level, and received many research fruit prize from government. His research interest is civil engineering.

Doctor Li Ma now works as a full professor in School of Business of Dalian University of Technology. She got her doctor degree in management from Nankai University, China in 2007. She has published more than 100 papers in domestic and foreign journals, and takes charge in over 20 scientific research projects of national and provincial level, as well as received many research fruit prize from government. Her research interests lie in project management and entrepreneurship.