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Enhancing Sustainable Community Developments: A Multi-criteria Evaluation Model for Energy Efficient Project Selection

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Abstract

Man consumes energy and community, the basic unit of urban development, is also an integrated energy-consuming unit. Sustainable community construction is a development model for local redevelopment which integrates culture and local features. Hence, incorporating a low-carbon concept into a sustainable community construction model will help reduce a community's carbon footprint. Community energy-saving polices can be effectively promoted by guidance, evaluation, feature development and sustainable management as well as heritage programs. This study applies Delphi method, analytic hierarchy process (AHP), and fuzzy logic in building a quantitative evaluation model for sustainable community construction low-carbon development effectiveness, to compare community low-carbon and energy saving development levels by calculating quantitative values as the basis for merits. In addition to testing the effectiveness of self-development of features, this study can also provide the government with a reference and criteria to evaluate the performance of low-carbon community construction projects.

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Keywords: Energy conservation; sustainable development; Delphi method; fuzzy logic; AHP

1. Introduction

The melting ice, draught, storms, floods, heat, cold and other abnormal weather conditions which were sporadic in the past have now become the norm. And the growing damage caused by each event is beyond

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everyone's expectations. Abnormal weather conditions directly affect lives and food production as well. Although there are a number of factors causing the deterioration of the living environment on the earth, the extra-high CO2 content of Earth's environment as a result of overdevelopment and overuse of energy is one of the most important factors causing unusual weather conditions. The harsh living environment issue we are facing now cannot be addressed by efforts of a few groups or a few countries. The energy-saving low-carbon lifestyle can no longer be considered as a concept, a slogan or a policy. Instead, it must become a part of everyday life so that the deterioration of the global environment can be slowed down.

Construction has been accused of causing environmental problems, ranging from excessive consumption of global resources, both in terms of construction and building operation to the pollution of the surrounding environment [1]. Based on estimates by the United Nations Environment Program, the building sector accounts for 30-40% of global energy use [2]. Thus, improving construction practices in order to minimize their detrimental effects on the natural environment has become an emerging issue [3-4]. The environmental impact of construction, green building, designing for recycling and eco-labeling of building materials have captured the attention of building professional across the world [5-8].

Community is the urban development basic unit as well as the unit of energy consumption measurement by the public sector. Hence, community construction and energy consumption can be closely correlated. Although the implementation of community construction policies may differ in countries around the world, the final goal of achieving old community redevelopment and renovation is universal. The implementation of sustainable community construction in Taiwan has integrated the concepts of people, culture, landscape, land and production. Therefore, the renovation and redevelopment of old communities should also take into consideration such features as community culture, geographical features and local products in addition to the construction of community hardware. A renovated community with unique local features will help overall urban development and develop diverse urban features as well as enhance the value of urban tourist attractions. Community construction is one of the community redevelopment policies of the government. Hence, it is easy to incorporate energy-saving low-carbon ideas into community construction as an important community redevelopment key factor. In this way, there is a positive impact on the control and management of lowering energy consumption while cultivating low carbon living habits in the redeveloped new community residents as well as being an example to promote low carbon ideas. Sustainable Community Development (SCD) aims to integrate economic, social and environmental objectives in community development. SCD is based on a consideration of the relationships between economic factors and other community elements such as housing, education, the natural environment, health, accessibility and the arts. SCD has emerged as a compelling alternative to conventional approaches to development. It is a participatory, holistic and inclusive process that leads to positive, concrete changes in communities by creating employment, reducing poverty, restoring the health of the natural environment, stabilizing local economies, and increasing community control.

According to the estimation from the BP Statistical Review of World Energy [9], the oil reserve may be exhausted by the year 2050 and the natural gas may be used up by the year 2070, while the coal mines may be depleted by the year 2130. Energy resources on the earth may be depleted in the future. At the same time over-mining and overuse of energy resources on the earth have been causing serious damage and pollution to the global environment, resulting in abnormal climate changes and unpredictable natural disasters. Every person should change past habits of energy consumption and ways of using energy while relevant governmental departments should formulate relevant energy saving incentives and penalties to help in implementing the low-carbon lifestyle. At the same time, energy exploitation and use should be appropriately restricted, so that it is possible to mend the deteriorating global environment.

At present, the monthly electricity consumption data, as compared with the same period last year, is the reward and punishment benchmark. The electricity tariff will be doubled if the power consumption is more than that of the same period last year. There will be rewards of electricity tariff reduction for reduction of use. Hence, punishment for energy consumption and CO2 production can be achieved by governmental policies. The rewards and punishments relating to energy saving can directly and effectively affect the behavior of the users. This study proposes to incorporate the factor of "low-carbon development" into policy planning for sustainable community construction in hopes that the government can make use of regular annual local construction fees to regulate the renovation and redevelopment process of the community as the urban basic unit in line with "energy saving and low-carbon" development policies, using construction subsidies as rewards. The quantitative evaluation model established in this study is a fair and objective evaluation model that can serve as the basis for the selection of an appropriate target community prior to implementation to develop a low-carbon community. In addition, the evaluation model can be used to validate the performance of the renovated community.

2. Model Overview

Fuzzy logic is an optimal tool for processing human fuzzy semantic quantitative issues, and also one of the important tools of development in the field of artificial intelligence (AI) technology. Fuzzy logic has been successfully applied in many different fields such as: automatic control, home appliances, unmanned aircraft, fingerprint systems, agriculture, meteorology and so on. In addition, as the fuzzy logic can accept uncertain, inaccurate and obscure human semantic information such as: good/bad, like/dislike and other logical relations, other than 0 and 1, fuzzy logic theory is best suited to deal with hard to quantize and complex to evaluate decision-making issues. The Delphi method is used to provide the latest knowledge, in line with current status and future development trends, through expertsin relevant fields, expertsin relevant governmental agencies and scholars with practical experience. After summarizing relevant preliminary evaluation factors from the literature, this study applies the Delphi method theory to work out evaluation factors with expert knowledge contents as the benchmarks for evaluation. Finally, we integrate the Delphi method with the fuzzy logic theory to build a quantized evaluation model as shown in Figure 1.

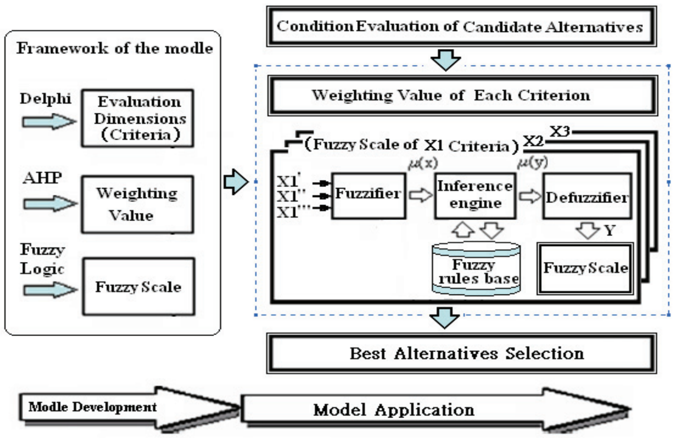

Fig. 1. The framework of the evaluation model

2.1. Delphi method

Developed in the 1950s by the Rand Corporation of the United States, the Delphi method is a method to help management and also a tool to predict the future. In particular, it has been widely applied in the current complex social life in collecting the opinions and judgment of individual members to form high quality decisions. The Delphi method is a way of interaction between experts to obtain the latest and most professional knowledge. It is not only applied to the prediction of future events [10]. The so-called "expert" should satisfy four conditions including "theory and practice", "capabilities to reflect different views", "capabilities of communications and research" and "lasting participating enthusiasm". In the process of applying the Delphi method, all participants should be anonymous in order to prevent them from being affected by other members while assuring they are not affected by various outside pressures in the process of making proposals for solutions. The Delphi method is to get consensus after an adequate questionnaire survey and discussion of experts from academics, industry and government, conducted anonymously and free from outside interference. The objective and professional Delphi method is one of the optimal basic methodologies to improve research reliability.

2.2. AHP theory

AHP is considered suitable to solve complex multi-objective, multi-factor decision-making problems [11]. AHP, first proposed by Saaty [12], is widely used in social, policy, engineering decision-making problems.

The AHP framework organizes logic and personal feelings or intuitive judgments so that researchers can map out complex situations as they are perceived. The AHP framework reflects the simple intuitive way one actually deals with problems, but it improves and streamlines the process by providing a structured approach to decision making [12]. On the basis of professional knowledge from experts, pair comparisons and matrix comparisons of criterion items at each level in the hierarchy framework are carried out. Additionally, consistency of the eigenvector derived from the comparison matrix can be checked; the weighting of each criterion item can be identified. Because the priority of each element is developed systematically and objectively, the AHP results are reliable to provide problem solutions for multi-factors decision-making situations.

2.3. Fuzzy logic

Fuzzy set theory was developed by Professor L. A. Zadeh of the University of California, Berkeley in 1965 and it is an optimal quantitative tool to deal with fuzzy phenomena and fuzzy language. The fuzzy logic theory based on the fuzzy set is mainly used to express and quantize some fuzzy concepts that cannot be clearly defined. It can have very good results in dealing with fuzzy language expressions, in particular. The fuzzy set theory expands the traditional mathematical dichotomy theory (set value is 0 or 1) to an infinite number of continuous set values (set values: between 0 ~1).

After determining the evaluation factors of the model by the Delphi method, we then apply fuzzy logic to build the model. During the model building process, a rigorous inference system should be completed first to assure effective and correct implementation and application of the evaluation model. The steps of building the fuzzy logic inference system are as follows:

- Define the fuzzy quantitative interval value and the high, moderate and low quantitative values.
- Define the output score fuzzy quantitative intervals and quantitative high, moderate, and low values.
- Define the membership functions of various evaluation factors and output scoring values.
- Define the semantic logic of the inference systemrelevance (effect) to describe the inter-relationship logics of various scenarios on the basis of different high, moderate, and low quantitative values.
- Establishment of rule base. Establish the inference systemaccording to the semantic logics of various scenarios as the knowledge rule base for the evaluation of model inference.

3. The Fuzzy Logic Inference System

Fuzzy logic inference can be divided into mamdani and sugeno systems. Generally speaking, the mamdani output values are continuous while the sugeno output values are discrete. We adopt the mamadani system in order to understand the continuous changes of output values. We divide the FLIS establishment process into steps including: the definition of fuzzy set of input evaluation factors/output values; IF-THEN rule Logic gate model, the definition of membership function and the defuzzification of output values [13].

3.1. Evaluation criteria

Residents must improve their community and reduce energy consumption. Therefore, the community redevelopment goal for “energy consumption” should take into account the following factors: urban greenery, and applications of natural resources, resource recycling and reuse, energy-saving materials, energy saving equipment as well as energy saving construction planning [14-16].

Table 1 Relative Weight of Various Evaluation Factors

Main-criteria	Weights	Sub-criteria	Weights
		Natural Environment	0.120
Energy Consumption	0.48	Energy Efficient Design	0.192
		Planting	0.168
		Development Convenience	0.091
Renovation Benefits	0.24	Living Environment	0.125
		Disrupted Facilities	0.024
		Local Cultural Attractions	0.101
Community Attractions	0.28	Community Participation	0.126
		Community Organizations	0.053
Sum			1.000

In addition to the aforementioned factors, the community redevelopment and renovation must take into consideration compliance with the uncertainties of redevelopment: serious population outmigration, community decline due to landslides/earthquakes or other natural disasters, development location selection and traffic factors, industrial pollution and so on. It can be learnt from the study of Ding [1] that: Four dimensions are considered for assessing the sustainability of construction: financial return, energy consumption, external benefits and environmental impact. The last three of those dimensions are previously noted development concepts and can be incorporated into two dimensions for the evaluation of sustainable community development: energy consumption and renovation benefits. In addition, since commercial profit is not the main goal of community developments, attractiveness is considered as an objective in this model instead of commercial activity. Finally, sustainable community construction is mainly aimed to develop the features of the community. Therefore, the following factors should be taken into consideration: community culture, local specialties, community participation, religious organizations, social welfare groups, harmonious consensus, and tourist attractions.

The above are the preliminary evaluation factors summarized on the basis of previous relevant literature. We furthermore used the Delphi method theory to select the evaluation factors for this research. There are a total 12 Delphi method invited experts for this study (four each from industry, the public sector and academics respectively). After two rounds of Delphi method questionnaires, we reached consensus after amendments and deletions regarding evaluation factors and relevant meanings. In the model development process, we used the AHP to calculate the relative weights of the evaluation factors as listed in Table 1. In addition, the impact meanings of various evaluation factors as listed in the table are to calculate the fuzzy quantitative values of various evaluation factors.

3.2. The set of fuzzy logic input and output factors

When calculating the fuzzy quantitative values of the three evaluation factors of energy consumption, renovation benefits, community attractions, it is to make quantitative processing of evaluation topics possible by using different degree values of the fuzzy set. As various evaluation factors have different impacts on the low-carbon development performance of sustainable community construction, therefore, the definition of fuzzy set can present the output value evaluation results.

The definitions of the upper and low limits of the evaluation scale of the three evaluation factors as well as the quantitative scale of output values are as shown in Table 2, Table 3 and Table 4. The measurement scale as defined in fuzzy logic is an artificial fuzzy scale. For example, in the "energy saving design and material" factor of energy consumption, 90 points and above represents "very good", 80 points for "good", 70 points for "ordinary", 50 points for "poor", and 30 points and below for "very poor". However, membership function is used in fuzzy logic scale to determine whether 70 points stands for "good" or "ordinary". Next, fuzzy logic inference system is applied for defuzzification and presentation of the quantitative value output results. This is the way of dealing with such issues by traditional evaluation model.

Table 2 Energy Consumption Input and Output Factor Fuzzy set Definitions

Input factor			Output	
Sub-criteria	Range	Fuzzy set	Description	Fuzzy set
Energy Efficient Design	0-100	very good; good; ordinary; poor; very poor	quantitative quality value	very good good ordinary poor very poor (0-100%)
Natural Environment	0-100	good; ordinary; bad (poor)		
Planting	0-100	good; ordinary; bad (poor)		

Table 3 Renovation Benefits Input and Output Factor Fuzzy Set Definitions

Input factor			Output	
Sub-criteria	Range	Fuzzy set	Description	Fuzzy set
Disrupted Facilities	0-100	good; ordinary; bad (poor)	quantitative quality value	high moderate low (0-100%)
Development Convenience	0-100	good; ordinary; bad (poor)		
Living Environment	0-100	good; ordinary; bad (poor)		

Table 4 Community Attractions Input and Output Factor Fuzzy Set Definitions

Input factor			Output	
Sub-criteria	Range	Fuzzy set	Description	Fuzzy set
Local Cultural Attractions	0-100	good; ordinary; bad (poor)	quantitative quality value	high moderate low (0-100%)
Community Participation	0-100	good; ordinary; bad (poor)		
Community Organizations	0-100	good; ordinary; bad (poor)		

3.3. The inference system and if-then rules

The fuzzy logic inference system conducts defuzzification of the results of inference according to the IF-THEN rules. The results are used to work out the quantitative output values. There are three input factors for quantitative evaluation of the first evaluation factor "energy consumption". The input factors fuzzy evaluation of the two evaluation factors of natural environment and the community greenery are classified into three states: good, ordinary, bad (or high, moderate and low). Therefore, there are a total of 9 different input states. In addition, the factors of energy saving design and equipment are classified into five states including very good, good, ordinary, poor, and very poor. Hence, there are a total of 45 different input states. The IF-THEN rules in the building of the FLIS are like the brain of a man. When the FLIS IF-THEN rules are established, the FLIS model has inference calculation capabilities. After the decision-maker grants an input value to each evaluation factor, the FLIS is then able to automatically calculate the quantitative performance evaluation values. The fuzzy quantitative evaluation configuration of the third evaluation factor of "community attractions" is similar. The input values of three influence factors can have a total of 45 different input states.

There are a total of three different factors affecting the quantitative evaluation of the second evaluation factor of "renovation benefits" and the fuzzy evaluation of input factors are divided into three states: good, ordinary and bad. Therefore, there are a total of 27 different input states.

3.4. Quantitative output value

The relative weights and fuzzy quantitative values after FLIS conversion of evaluation factors are the basis for the evaluation of the low carbon development performance of the "sustainable community construction". Higher AHP and FLIS scores represent better performance. Figure 2 illustrates the quantitative evaluation 3D relations of various factors under mutual inferences. The mutual relations between various evaluation factors can be interpreted from the 3D relations.

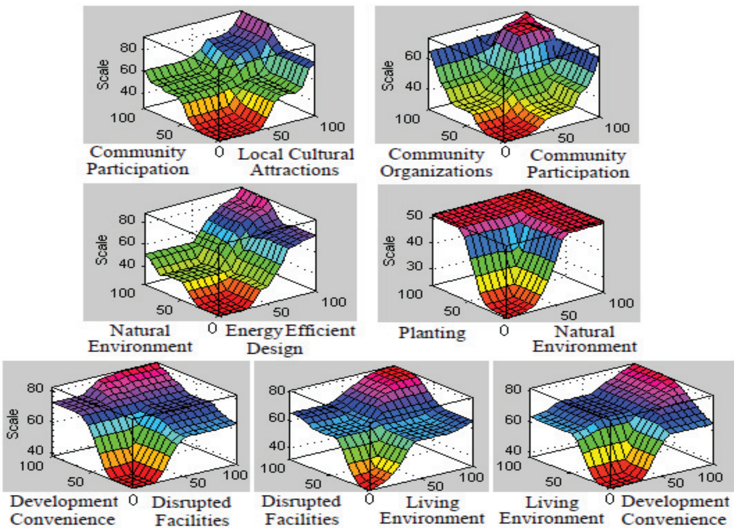

Fig. 2. Quantitative evaluation 3D relations affecting different criteria

Table 5, 6, 7 illustrate the optimal and the poorest fuzzy inference output quantitative results. In addition, the quantitative values as shown in Table 5, 6, 7 can match proper quantitative output values due to the status of input values [input evaluation status can be quantitative value or vague wording such as: good (high), ordinary (moderate), bad(low)]. Hence, prior to project evaluation, the model may first calculate and compare the quantitative values as the basis for decision making to help the decision making efficiency and effects.

Table 5 Energy Consumption Criterion Optimal and Poorest Quantitative Scores

Sub-criteria	Optimal fuzzy inference	Poorest fuzzy inference	The case study
Energy Efficient Design	high (H)	low(0)	70
Natural Environment	high (H)	low(0)	80
Planting	high (H)	low (0)	80
output quantitative scoring	89.7	24.1	73.6

Table 6 Renovation Benefits Criterion Optimal and Poorest Quantitative Scores

Sub-criteria	Optimal fuzzy inference	Poorest fuzzy inference	The case study
Disrupted Facilities	high (H)	low (0)	50
Development Convenience	high (H)	low (0)	50
Living Environment	high (H)	low (0)	50
output quantitative scoring	84.4	29.1	68.7

Table 7 Community Attractions Criterion Optimal and Poorest Quantitative Scores

Sub-criteria	Optimal fuzzy inference	Poorest fuzzy inference	The case study
Local Cultural Attractions	high (H)	low (0)	50
Community Participation	high (H)	low (0)	50
Community Organizations	high (H)	low (0)	50
output quantitative scoring	93.5	25.3	48.7

4. Case Study

Community construction and redevelopment often request governmental project subsidies to speed up the featured community development and upgrading. Hence, in this section, the evaluation model developed in this study can be used to help the decision-making regarding the selection of community construction projects. At present, three community construction and redevelopment projects have applied for governmental grants. The governmental grants require fair, just and open procedures and methods. Hence, the government needs badly a set of quantitative evaluation tools coupled with energy-saving low-carbon policy analysis tools to help decision making. According to the evaluation model developed in this study, the examples, as shown in Table 8, can select proper development projects after comparison or evaluate the performance of completed development projects.

Table 8 Evaluation of Project 1 to Project N and Output Values Calculated by the Proposed Model

Main-criteria	Sub-criteria	Project 1			Project N		
		Fuzzy Input	Fuzzy Output	Weighted Output	Fuzzy Input	Fuzzy Output	Weighted Output
Energy Consumption (Wi=0.48)	Natural Environment (Wi=0.120)	80	73.6	73.6*0.48 =35.328	70	84	84*0.48 =40.32
	Energy Efficient Design (Wi=0.192)	70			90		
	Planting (Wi=0.168)	80			80		
Renovation Benefits (Wi=0.24)	Development Convenience (Wi=0.091)	90	80.6	80.6*0.24 =19.344	85	79.1	79.1*0.24 =18.984
	Living Environment (Wi=0.125)	60			60		
	Disrupted Facilities (Wi=0.024)	70			70		
Community Attractions (Wi=0.28)	Local Cultural Attractions (Wi=0.101)	70	77.1	77.1*0.28 =21.588	70	77.1	77.1*0.28 =21.588
	Community Participation (Wi=0.126)	70			70		
	Community Organizations (Wi=0.053)	90			90		
Evaluation of Project value		35.328+19.344+21.588=76.26			40.32+18.984+21.588=80.982		

5. Conclusions

National and regional construction projects bring about economic development. At the same time, such projects are one of the major causes of world energy consumption. Hence, how to conduct integrated evaluation of energy use and economic development prior to construction to blend the philosophy of low-carbon energy-saving the construction rather than impede the construction is one of the most pragmatic low-carbon energy-saving implementation approaches.

Community is an important basic unit of urban development. Community development plays an important role in urban construction and development and affects the residents' habits of energy use and lifestyles. Hence, the sustainable community construction integrated evaluation model incorporated with the philosophy of small carbon footprint energy conservation proposed in this study can effectively help community planning, designing units and the government in the selection of community construction projects to blend the ideas of low carbon residue energy-saving into community development projects prior to construction. In addition to the performance evaluation of community feature development, the model proposed in this study can provide the government with a reference and performance evaluation benchmark regarding the promotion of low carbon community construction projects. The model can help governmental decision making to select community construction projects that can integrate objectives including “energy consumption”, “renovation benefits”, “community attractions” in fair, just and open procedures through the objective quantitative evaluation approach before granting support. The method is not only in line with the idea of community development, but also promotes and guides energy-saving urban construction development and low-carbon energy-saving habits of residents gradually. In the long run, the energy conservation and carbon reduction effects will be more significant.

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