Chapter 34
Evaluation of Green Residence Using Integrated Structural Equation Model with Fuzzy Theory

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Abstract The feasibility of constructing green residential houses was investigated by analyzing questionnaires designed to collect relevant information coped with indices and design characteristics for green residential houses. The questionnaire answers were analyzed using the SPSS18.0 software to carry out descriptive statistical analyses, and the SEM with fuzzy theory to perform model suitability analyses. The objective of these analyses is to evaluate and identify the factors that practical affect the construction of green residential houses. Results of analyzing questionnaire answers reveal that as high as 80 % of the general public agrees to purchase green residential houses. The results obtained in this research indicate that these characters must be considered as important factors when developing green residential houses with qualities meeting demands of the general public so that a win–win situation can be achieved for both developer and consumers.

Keywords Fuzzy theory · Green residential houses · Residential houses · Structural equation model

34.1 Introduction

Green environmental protection is currently a topic that is concerned the most in our society. In 1996, the Administrative Yuan established the "National Sustainable Development Committee" and actively promoted the policy of developing

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E. Qi et al. (eds.), *The 19th International Conference on Industrial Engineering and Engineering Management*, DOI: 10.1007/978-3-642-38391-5_34,

green buildings as proclaimed in "Building White Paper" published earlier in the same year. Further, the Administrative Yuan approved "Project to Promote Green Buildings" on March 8, 2001 and implemented the "Green Building Logo" system (National Council for Sustainable Development Network). Although started a little late, these implementations led to obvious accomplishments; Taiwan became the fourth nation in the world that officially put certification of green buildings into practice. Therefore, the factors that affect the practicality of constructing green residential houses are studied in this research so that the difficulties that may be encountered to promote green residential houses will be identified. The results will provide valuable recommendations to be referenced by Government for future promotion of green residential houses in Taiwan.

34.2 Literature Review

In recent years, a green upsurge in construction is on the rising internationally; variations nations and relevant organizations actively promote the implementation of green products in daily applications that enable the popularity of green residential house internally. Our nation also actively promotes green buildings through rewarding and subsiding the design and construction of green buildings. However, the percentage of green residential houses on the real estate market is not as high as expected. In this research, the practicality of implementing green residential houses will be studied to identify the future trend for promoting green residential houses that is accepted by both builders and buyers.

34.2.1 Definition of Green Residential Houses

Housing is one of the basic needs to satisfy the six people's livelihood of eating, clothing, housing, transportation, education and entertainment; traditional housing simply provides sheltering. With social and economical advances, the need for quality residential houses becomes increasingly demanding. In addition to providing a safe and comfortable sheltering, green residential houses are becoming a concerned emphasis. The definition of green residential houses is discussed in this section.

a. Definition of Residence

"Residence" refers to the house that provides either a permanent or temporary shelter for the occupant to live and perform daily activities. As defined in Wikipedia (Baidu Baike 2011), a residence is an establishment where it was originally or currently being used by a host as their main place of dwelling or home. This is used as the definition of "residence" in this research.

b. Definition of Residential House

Green buildings that recently emerge in Taiwan cover a wide range of buildings. Green residential house is a part of green building. Although most scholars have proposed the definition of “green residential houses”, this term has not been clearly defined. Based on literature information, the “green residential house” is defined in this research as “the residential house that is constructed based on the concept of low carbon with natural ventilation and lighting to reduce energy requirement and wastewater discharge”. A green residential house is a house that can breathe by itself in some sense.

c. Characteristics of Green Residential Houses

A green residential house has the following integrated characteristics:

1. Ecological Consideration: The broad sense of this consideration was proposed in 1997 by Kuo and Kuo (1997) based on the viewpoint of ecological environment. It is based on the overall consideration to target energy source protection, climate regulation, and resource implementation for accomplishing the objective of ecological environment. A more specific definition is applying the characteristics of cultivated plants and green technology to reinforce or improve the building and foundation environment. The above statements are integrated to define the ecological consideration of green residential houses as: the combination of local environment and relevant climate to make a place for human living using natural design to reduce impacts on environment, and achieve ecological balance.
2. Energy Saving Consideration: In 1999, the Architecture and Building Research Institute, Ministry of the Interior (Taiwan) (Lin 1999), proposed four groups of green building indices; energy savings is an important index group. If a residential house meets the requirement of a green residential house, it must have the characteristics of achieving energy saving. Hence, in this research, the green residential energy saving features include facilities that lead to savings of water and energy. These features may include solar water heater, and water-saving apparatus and pipeline design to achieve conservation of water, energy and other natural resources.
3. Water Reducing Consideration (Taiwan Architecture and Building Center): For each square meter of reinforced concrete buildings constructed in Taiwan, about 1.8-kg dust is produced that seriously threatens human health. A medium-height residential building generates about 0.14 cubic meters of solid wastes during the construction period; if demolished and removed later, the building will generate 1.23 cubic meters of more solid wastes. Thus, the ultimate treatment and disposal facilities are heavily loaded by the large quantity of construction wastes (Web-site of Taiwan Architecture and Building Center). Therefore, green residential houses are constructed with natural materials that are environmentally friendly and recoverable to reduce the waste quantity so that the impact on environment can be alleviated.

4. Health Consideration: Lin (2005) proposed that the green buildings is an ecological, energy-saving, waste-reducing and healthy building indicating that promoting the health of occupants is an important characteristics of a green residential house. The quality of living environment affects to a great extent the physical and mental health of the occupants. Green residential houses apply the design of natural ventilation and external solar shed to reduce the energy consumptions on indoor artificial heating, ventilation and air conditioning as well as lighting while providing a healthy and comfortable living environment.
5. Sustainable Consideration: Kuo and Kuo (1997) proposed that during its life cycle, a building should provide the optimal and most comfortable and healthy living environment with the lowest energy consumption, most efficient management and resource application, and the least damages to environment. Hence, symbiotic existence of human, building and environment with mutual benefits can be achieved to accomplish sustainable development. In this research, the sustainable characteristics of green residential houses is based on the concept of sustainable development design to alleviate environmental damages, and to assure that future environmental development is compatible with the earth so that sustainable development of our living environment is assured.

34.2.2 Structural Equation Model

Structural Equation Modeling (SEM) is also called the "Analyses of Covariance Structure or Linear Structure Equation" that is a statistical method for analyzing case-and-effect results and examining assumptions (Chen 2007).

a. Application of Structural Equation Model (SEM)

Huang (2006) has pointed out that SEM is the most important emerging statistical method for quantifying information in modern sociology; it has been extensively applied in the various fields such as management science, psychology and economics.

b. Chartered Financial Analyst (CFA)

CFA is used for testing validity to examine the significant and structure of latent variables.

The above introduction of SEM reveals that SEM is a research and analysis method of statistical analysis technology for dealing with complicate multivariate information and data. In this research, the CFA available in SEM is used to develop factors for evaluating green residential houses so that the results are reliable and valid.

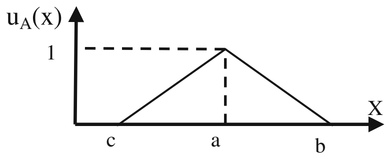


Fig. 34.1 The membership functions of a triangular fuzzy number

34.2.3 Fuzzy Theory

The Fuzzy Theory that was proposed by Prof. Zadeh in 1965 emphasizes that the concept of human thinking, inferring and cognitive ability is somewhat fuzzy for solving uncertain and fuzzy problems encounter in a real world. Chien (2009) considered that the fuzzy theory can be used for solving decisions not only for policy making but also for daily life related matters such as fuzzy control of variable frequency air conditioning unit. In recent years, the fuzzy theory has been integrated with many other methods including grey relational analyses, TOPSIS and AHP, among the many others.

Values of the fuzzy semantic variables are also called semantic values; they can be expressed by defining the base variable of a fuzzy membership function (Zimmermann 1987), or the membership function can be considered as quantified attributes of semantic values. The triangular fuzzy number A in the region of real number R indicates that any $x \in R$ is designating a number $u_A(x) \in [0, 1]$, and that:

$$u_A(x) = \begin{cases} (x-c)/(a-c), c \le x \le a \\ (x-b)/(a-b), a \le x \le b \\ 0 \end{cases} \tag{34.1}$$

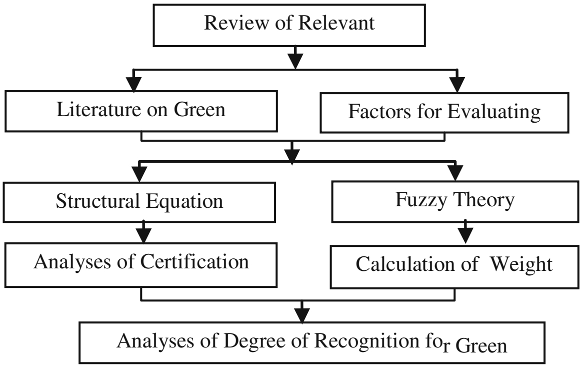
The triangular fuzzy number can be expressed by A = (c, a, b) with the function value between c and b of $u_A(x)$, and the maximum membership of 1. The region between c and b refers to the possible upper and lower boundaries of the evaluation data. Regions between c and a, and between a and b reflect the fuzziness of the data as shown in Fig. 34.1.

Based on the above statements, the fuzzy theory is applied in this research for evaluating the degree of importance attached to the various factors of green residential houses. The importance of these factors is prioritized as the standards for accessing green residential houses.

34.3 Methodology

The objective of this research is to apply the combined structural equation model (SEM) and fuzzy theory for investing the possibility of developing green residential houses in Taiwan. Additionally, questionnaires are distributed to residence living in Taichung (Taiwan) region for understanding their need and degree of

Fig. 34.2 Research structure



recognition of green residential houses, and the feasibility of developing green residential houses in Taiwan.

34.3.1 The Research Structure

Based on the viewpoint of consumers, this research is carried out for investigating the factors of green residential houses that satisfy the need of general public. Review of literature leads to the factors that influence the construction of green residential houses as included in the following research structure (Fig. 34.2):

34.3.2 Research Model

Based on the review of literature on green residential houses, the factors used in the model for evaluating green residential houses are grouped into three major dimensions: "Indoor Environment", "Energy Saving Facilities" and "Community Environment" as illustrated in the follows:

1. Indoor environment: The occupants of the green residential house enjoy a comfort and leisure life provided by appropriate residential lighting, ventilation and insulation.
2. Energy saving facilities: The objective of green residential house is achieved by providing energy saving features such as electricity saving, water saving and noise insulation.
3. Community environment: The residence of a community can enjoy the green residential houses only if the community environment and facilities are well planned such as wastewater treatment facilities, green zone, storm water drainage, and facilities to recover garbage.

34.3.3 Fuzzy Theory Procedures

The fuzzy theory that is used for solving uncertain and fuzzy problems encountered in the real world is implemented in this research using the following procedures.

Procedure 1: A fuzzy preference order matrix is established to evaluate the semantic variables expressed by K professionals and experts based on each criterion. After evaluating the m projects (Ai, i = 1,…, m) based on n criteria (Cj, j = 1,…,n) for k professionals and experts, geometric mean is used to integrate the evaluation results to yield fuzzy preference order matrix as follows:

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{21} & \cdots & \tilde{x}_{21} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \forall i,j \tag{34.2}$$

where: $\tilde{x}_{ij} = \left(a_{ij}, b_{ij}, c_{ij}\right)$ is a triangular fuzz number that represents the fuzzy value of ith prospective project in the jth criterion. The following equation is used to normalize the fuzzy matrixbb $\tilde{R} = \left[\tilde{r}_{ij}\right]_{m\times n}$:

$$\begin{aligned} \tilde{\mathrm{r}}_{\mathrm{ij}} &= \left(\frac{\mathrm{a_{ij}}}{\mathrm{c_j^+}}, \frac{\mathrm{b_{ij}}}{\mathrm{c_j^+}}, \frac{\mathrm{c_{ij}}}{\mathrm{c_j^+}}\right),\ \mathrm{j} \in \mathrm{B}\ \mathrm{c_j^*} = \max_{\mathrm{i}}\ \mathrm{c_{ij}}\ \mathrm{if\,j} \in \mathrm{B} \\ \tilde{\mathrm{r}}_{\mathrm{ij}} &= \left(\frac{\mathrm{a_j^-}}{\mathrm{a_{ij}}}, \frac{\mathrm{a_j^-}}{\mathrm{b_{ij}}}, \frac{\mathrm{a_j^-}}{\mathrm{c_{ij}}}\right), \mathrm{j} \in \mathrm{C}\ \mathrm{c_j^-} = \max_{\mathrm{i}}\ \mathrm{a_{ij}}\ \mathrm{if\,i} \in \mathrm{C} \end{aligned} \tag{34.3}$$

The five classes of fuzzy semantic conversion scale proposed by Chen and Hwang (1992) are used to evaluate the importance attached to green residential houses to convert the semantic expression into fuzzy numbers as shown in Table 34.1.

Procedure 2: Weighed coefficients: The weight of each evaluation condition can be calculated; the weight of evaluation attribute is $w_i = (w_1, w_2, \ldots, w_m)$. In this research, a simpler gravity method developed by Yager (1980) is used to perform fuzzy sorting. Results of equation derivation show that the sorting of centroid fuzzy values for the fuzzy triangular function can be expressed by Eq. (34.4). The

Table 34.1 Correspondence of fuzzy semantic expressions to fuzzy number

Evaluation scale	Fuzzy semantic expression	Fuzzy number
1	Significantly not important	(0,0,0.3)
2	Not important	(0,0.25,0.5)
3	Neutral	(0.3,0.5,0.7)
4	Important	(0.5,0.75,1)
5	Significantly important	(0.7,1,1)

Source of Information (Chen and Hwang 1992) opinions expressed by experts are integrated using triangular fuzzy numbers Buckley (1984), and Eq. (34.5) is used to calculate the geometric mean of the results. The sorting of the centroid fuzzy for the integrated fuzzy triangular function is expressed as follows:

$$R(\tilde{A}) = \frac{1}{3}(l_A + m_A + u_A) \tag{34.4}$$

$$W_i = \left(\prod_{i=1}^{n} R(\tilde{A})\right)^{\left(\frac{1}{n}\right)} i = 1, 2, \ldots, n \tag{34.5}$$

Procedure 3: Preference Aggregation: The algorithm using the two triangular fuzzy numbers calculation, $\tilde{a}_1 = (a_1, a_2, a_3)$ and$\tilde{b} = (b_1, b_2, b_3)$ as proposed by Zadeh.

Procedure 4: Normalized weighted fuzzy matrix is developed:

$$\tilde{V} = \lfloor \tilde{v}_{ij} \rfloor_{\mathrm{m} \times \mathrm{n}}, \mathrm{i} = 1, 2, \ldots, \mathrm{m},\ \mathrm{j} = 1, 2, \ldots, \mathrm{n} \tag{34.6}$$

where: $\tilde{v}_{ij} = \tilde{r}_{ij} \times \tilde{W}_{ij}$ with value between [0,1]; $\tilde{W}_{ij}$ is the weighted fuzzy value of the jth criterion.

Procedure 4: Defuzzification: There are many method of defuzzification. In this research, the method proposed by Chen and Hsieh (1999) is used by assigning $A_i = (a_i, b_i, c_i)$, i = 1,2,…,m, as m triangular fuzzy numbers. R(Ai) indicates the representative value of triangular fuzzy number for the ith person being evaluated. The equation is:

$$R(A_i) = \frac{a_i + 4b_i + c_i}{6} \tag{34.7}$$

34.4 Analyses

Through reviewing literature on green residential houses, relevant residential factors are summed up. After analyzing the information collected using questionnaire and studying the sample structural analyses, confirmation factor analyses, and fuzzy theory, the factors that can be implemented and the items that the general public prefers when purchasing green residential houses can be found. The questionnaire results indicate that about 80 % of the general public has the willing to purchase green residential houses but wishes to pay not more than 10 % higher than a regular house with 5 % higher cost being the most acceptable.

34.4.1 Data Analyses

The SPSS 18.0 statistical software is used in this research for carrying out statistical analyses. The statistical methods include descriptive statistical analyses, reliability analyses and the various examinations. The overall model analyses are performed using AMOS 17.0, and finally the fuzzy theory is applied for find out the practicality of green residential houses and the order of importance for factors considered by the general public for purchasing green residential houses.

34.4.2 Factors Important to the Buyers of Green Residential Houses

The results obtained by perform the two-stage five-factor examinations are used to confirm the validity of the three assumptions proposed in this research. The explanations are provided in the following paragraphs:

1. Constructing green residential houses is an external latent variable that is reflected by the three internal latent variables, i.e. indoor environment, energy saving facilities and community environment. All coefficients obtained by conducting CFA examinations show are greater than 0.7 confirming that green residential houses can be evaluated using these three dimensions.
2. Indoor environment is an internal latent variable that is reflected by observing three variables.
3. Energy saving is an internal latent variable that is reflected by observing three variables.
4. Community environment is an internal latent variable that is reflected by observing four variables.

34.4.3 Fuzzy Theory

The fussy theory and the centroid method are used to determine relevant weighted value for investigating the factors important to constructing green residential houses in the Greater Taichung (Taiwan) region. Procedures for conducting the fuzzy theory are as follows:

Procedure 1: Standards for evaluation are established. In this research, the evaluation factor in "Dimensions for constructing green residential houses" are used to carry out the evaluation of factors affecting green residential houses as shown in Table 34.2.

Procedure 2: After the original matrix is developed, Eq. (34.5) can be used to evaluation the weight of attributes by calculating the fuzzy value of the various evaluation dimensions as shown in Table 34.3. The geometric average is then

Table 34.2 Factors for evaluating green residential house

Evaluation dimensions		Evaluation factors	
C1	Indoor environment	A1	Residential lighting
		A2	Residential ventilation
		A3	Residential insulation
C2	Energy-saving facilities	B1	Electricity saving facilities
		B2	Water saving facilities
		B3	Noise insulation
C3	Community environment	D1	Wastewater treatment facilities
		D2	Green area
		D3	Drainage
		D4	Facilities for recovering garbage

Table 34.3 Overall fuzzy evaluation results

Evaluation factors		Fuzzy number		
A1	Residential lighting	0.34	0.57	0.78
A2	Residential ventilation	0.31	0.54	0.75
A3	Residential insulation	0.30	0.53	0.74
B1	Electricity saving facilities	0.34	0.57	0.78
B2	Water saving facilities	0.36	0.59	0.79
B3	Noise insulation	0.38	0.61	0.81
D1	Wastewater treatment facilities	0.36	0.60	0.81
D2	Green area	0.29	0.52	0.73
D3	Drainage	0.32	0.55	0.76
D4	Facilities for recovering garbage	0.34	0.58	0.78

Table 34.4 Weight and ordering of green residential housing

Evaluation factors		Weight	Ordering
A1	Residential lighting	0.535	5
A2	Residential ventilation	0.500	8
A3	Residential insulation	0.490	9
B1	Electricity saving facilities	0.533	6
B2	Water saving facilities	0.550	3
B3	Noise insulation	0.571	1
D1	Wastewater treatment facilities	0.560	2
D2	Green area	0.482	10
D3	Drainage	0.513	7
D4	Facilities for recovering garbage	0.537	4

calculated to obtain the weight value and order of magnitude for various factors Table 34.4.

Procedure 3: Eq. (34.7) is used to defuzzify, calculate and sort. Order of factor important to the construction of green residential houses is shown in Table 34.5.

Table 34.5 Results of fuzzy analyses on green residential houses

Evaluation factors		Fuzzy solutions	Ordering
A1	Residential lighting	0.569	1
A2	Residential ventilation	0.537	2
A3	Residential insulation	0.527	3
B1	Electricity saving facilities	0.567	3
B2	Water saving facilities	0.583	2
B3	Noise insulation	0.604	1
D1	Wasterwater treatment facilities	0.593	1
D2	Green area	0.517	4
D3	Drainage	0.548	3
D4	Facilities for recovering garbage	0.572	2

Data in the above table reveal that the need of a green residential house with energy saving feather by the general public is relatively high. As the indoor environment is concerned, the residential lighting, which is related to energy savings, is also emphasized by the general public indicating that the general public has already acknowledged the importance of energy resources. Hence, further planning of green residential houses needs to emphasize the energy saving function in order to satisfy the need of consumers.

34.5 Conclusions

Results of investigation and analyses obtained in this research show that more than 80 % of the general public in Taiwan accepts green residential houses so that developing green residential houses is feasible. The general public also expresses that the green residential house costs less than 10 % more than a regular residential house so that 10 % cost difference is accepted. Additionally, developing green residential houses needs the cooperative efforts of government, developer and consumer. The government has to promote programs for dissimilating information on green residential houses, and encourage developers to construct more green residential houses through a rewarding system so that the general public is more willing to purchase green residential houses. Effective promotion of green residential houses will enable developer to base on specifications of green residential houses for selecting appropriate materials and methods to construct residential houses that are healthy and comfortable with low pollution and reduced energy consumption. The concept and advantages of green residential houses are dissimilated to the general public so that when purchasing residential houses, consumers consider green residential houses as the primary choice, and are willing to pay a little more for green residential houses. The idea of green residential houses can thus be implemented in Taiwan.

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