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行政院國家科學委員會專題研究計畫成果報告(精簡版)

多準則決策分析應用於住宅社區永續發展之評價

The Application of Multi-Criteria Decision Analysis for the Assessment of Sustainable Development to Residence Community

中文摘要

當人類居住環境的發展與管理聚焦於永續發展的全球趨勢下，其「全球思考、地區行動」的概念必須轉化成具體、確切的執行。因此，為能有效落實居住環境的永續發展，必須依照地方特質建立起該地區行動的準則。在執行上，首先需釐清概念於地理空間單元上實踐的對應；進而就其特性尋求客觀有效的衡量方法。隨著時代的快速變遷，工業化、都市化與全球化使得具高度社會互動、聯合分擔與地理場所混合使用特質之台灣傳統社區，因地狹人稠而朝向高層化、高密度集中之集合住宅形式發展，並轉變為強調滿足自我居住品質與私密安全之群聚式單一使用的「集合住宅社區」。本研究先行透過相關研究文獻回顧與整理，綜合歸納出影響集合住宅社區永續發展之相關可能因子；爾後，再透過模糊德爾菲法（Fuzzy Delphi Method; FDM）從中篩選出衡量發展之確切依循準則。而，為考量評價時於相關構面間與準則間可能存在有複雜的相互影響關係，特藉由專家群體討論，並援引具有效解決多屬性決策問題能力之分析網路程序法（Analytic Network Process; ANP）以資釐清；並藉以建構出一可將主觀、質性感知問題轉化為客觀、量化分析的評價模式。研究結果可將抽象的永續概念轉換成清晰的網路評量架構，其具客觀性與可操作性之成果不但可作為落實永續概念的基礎、與政府相關政策制訂時之參考，並可成為未來於規劃發展與實踐時之導引。

關鍵詞：模糊德爾菲法、分析網路程序法、集居環境永續發展、集合住宅社區

Abstract

When the trend of development and management of human residence environment becomes focusing on the concept of sustainable development (SD) over the world, the concept of “thinking globally, action locally” needs to be transferred into specific and practicable implementations. Hence, in order to fulfill SD to residence environment effectively, local action principle needs to be established based on the location’s characteristics. Besides, in the implementation, the correspondence of the concept for the geographical space must be distinguished firstly, and then the objective and effective evaluation method must be developed. With the rapid changing time and dense population with small land area, the dwelling in Taiwan has been developed toward the type of housing with high-rise, high density and centralization. In addition, industrialization, urbanization and globalization have pushed traditional community, which possessed the characteristics of high social interaction, shared ties, and geographical location mixed-use, into “housing community (HC).” The HC emphasizes the satisfaction of personal living quality, privacy and safety, and is in the form of cluster and single-use. In order to guide and implement SD effectively, this paper first searches the relevant possible impact factors (PIFs) of the SD for the HC. Fuzzy Delphi method (FDM) is applied next to extract the factors for further analysis. Furthermore, since there is complex interdependence among objectives and among criteria, this research examines the relationship thorough expert group discussion and form the evaluation model. The analytic network process (ANP) method, which can solve multi-attribute decision analysis (MADA) problems effectively, is employed next to solve the model. Through the systematic analysis, a subjective and qualitative perception problem can be transformed and solved in an objective and quantitative evaluation model. As a result, the abstract concept of SD can be applied in a distinct network model suitably. The conclusion and results obtained from the operation of the evaluation model not only can be a foundation to implement the sustainable concept and a recommendation for government's related policy making, but also can be a guidance for planning and practicing in the future.

Keywords: Fuzzy Delphi method (FDM); Analytic network process (ANP); Collective residence environment sustainable development; Housing community (HC)

1. Introduction

Sustainable development (SD) has been focused on residential environment in the world in turns of development and management in the past twenty years. Awareness of its concept/definition is abstract. Conceptual work of "thinking globally, action locally", therefore, should be transferred into specific and applicable approach. Implementation of SD effectively in residence environment should have two structural concerns (Chan & Wu, 2003; Chan & Huang, 2004). First, the concept of space of geographical scale for action should be included (Lee & Huang, 2007). Second, an objective and valid measurement method should be developed.

Housing community (HC) designed with collective dwelling type has become a basic construction unit in residential environment and urban development. This is due to the limitation of land and condensed population in Taiwan. Furthermore, government should define residence and community clearly in order to move toward SD under rapid transition based on highly urbanization, industrialization and technology (National Council for Sustainable development, 2000). In other words, HC is the response to space of geographical scale for action (Beatley & Manning, 1997; Forman, 1995).

Establishment of evaluating indicators is an essential work to transfer the concept effectively into developing space units (Frasera et al. 2006; Spangenberg et al., 2002). Evaluation model can then be developed (Lin & Lee, 2005; Yuan et al. 2003). Nevertheless, in the process of operating performance model, there are complicated interrelationships existing among various factors (Chan & Huang, 2004; Maclaren, 1996). Such a characteristic belongs to multi-attribute decision analysis (MADA). Many works done on MADA (see Chen & Liu, 2007; Lee & Li, 2006) showed that the fuzzy Delphi method (FDM) can extract definite factors effectively from related attributes. The extracted factors can then be criteria for measurement. In addition, the analytic network process (ANP) has the ability to handle interdependency among attributes and criteria.

The purpose of this paper is to establish a distinct, objective and applicable evaluation model that transforms abstract SD concept based on characteristics and requirements of local basic unit. The results could examine the implementation of the SD concept more specifically and practically. Moreover, it will also offer sufficient planning and executing guidance to local residential environment development in the future.

2. Literature review

2.1 Transition of Community

Due to the influence of traditional neighborhood unit theory, community in the past not only provided function of residence but also work, culture, education, social life and certain scale of commercial activity. It was a mixed-use living environment and a basic unit for social development and urban construction (Churchill & Baetz, 1999; Mason & Cheyne, 2000).

With swift changing in time, industrialization reduces the dependence of people on community. Convenient transportation under urbanization also lengthens the distance between working location and residence. Frequent communication and network cooperation in globalization collapse the pattern of living interaction (Birkeland, 2002). These trends change the living style from the traditional community with characteristics of social interaction, shared ties and geographical location (Hillery, 1955) to self-satisfaction, privacy, and an emphasis on occupational interest than community interest, and gradually to an isolated and sterile accommodation (Wight, 1995; Churchill & Baetz, 1999). In Taiwan, a small island with condensed population, the transition becomes even apparent and housing community (HC) has become a dominant developing form. However, due to broadened phenomena of contemporary community (e.g. increased mobility and electronic communication) and conceptual abstract association (e.g. scientific community) (Birkeland, 2002), group residential livelihood in the past gradually evolves into self-satisfaction, independent livelihood with indifference and rare interaction (Hung & Wang, 2006). HC, a basic unit of development with local characteristic, reflects an appropriate correspondence with the geographical space unit.

2.2 Sustainability Indicators and Impact Factors

Since 1980s, SD has emerged as a popular solution to the problem of meeting the material needs of a rapidly growing population (Bridger & Luloff, 1999). Many scholars attempt to apply sustainability to the issues of residence community (Bridger & Luloff, 1999; Barton, 2000; Lafferty, 2002; Weber, 2003, Chan & Huang, 2004).There were many research works have explored the restriction and utilization of resources and ecology, the living attitude/style and needs/quality of residents, and the policies and management in operation and development. As a result, concepts, such as "green community" (Lin & Lee, 2005), "ecology community" (Zhang & Shyng, 2004) and "healthy community" (Farmer et al., 2003), are developed. However, no matter what the research results are, as stated by Lee & Huang (2007), it is necessary to establish evaluation criteria for creating a more livable and compatible environment.

Before SD was defined by WCED in 1987, Van der Ryn & Calthorpe (1986) had already discussed sustainable community. Later on, many works also studied the issue. The Sustainable Seattle (1998) listed 40 indicators of sustainable community under four dimensions: environment, population & resources, economy, and culture & society. Beatley (1998) claimed that a sustainable community should contain principles of safety, environmentally-friendly, symbiosis, consensus, ethic, and equity. Moreover, Bridger & Luloff (1999) proposed that typical and ideal sustainable community should be defined in five dimensions, such as self reliance etc. Barton (2000) also listed five dimensions to explore the local sustainability (e.g. social equity and health). In addition to the above works, numerous researches have similar analysis and detailed discussion, including Roseland (2000), Weber (2003), Farmer et al. (2003), and ODPM (2004).

Some researches focused on local indigenous needs and characteristics are found. Chan & Wu (2003) and Chan & Huang (2004) listed eight rules, such as self-regulation and multiple-utilization, of bio-cybernetic to define 26 variables to be criteria of sustainable community. Lin & Lee (2005) believed community is the basic administrative unit for people living, work and enjoy their life. From questionnaire analyses and group discussions, the authors established core indicators of sustainable community indicators, including three main dimensions, five sub-categories, and ten indicators. Moreover, Wu et al. (2006) presented four dimensions and associated benchmarks to evaluate sustainable community management.

2.3. Existed Evaluation Models and Methods

From literature review, we can understand that there are extensive influencing dimensions and attributes for the SD of HC. Thus, this is a MADA problem. There were numerous methods conducted in the past, such as ranking technique, scoring, AHP, and mathematical models including goal programming, dynamic programming and so on (Wey & Wu, 2007).The above methodologies can deal with simple and simplified thinking models. However, to solve the complex interrelationship among criteria for the abstract SD concept, the above techniques are not adequate enough.

Most of the measuring approaches and evaluation models focusing on this field tried to establish influencing factors, indicators/criteria first (see Innes & Booher, 1999; Andrew & Carroll, 2001; Bell & Morse, 2004). Reed et al. (2006) set up a learning process by integrating approaches of top-down from expert-led and bottom-up from community-based. The criteria and SD goal of HC form a loop structure, and community-driven participatory methods (CDPM) is adopted for evaluation. Chan & Hung (2004) considered variables for community development, and then engaged in systematic evaluation research by sensitivity model (SM). Moreover, Taylor (2001) made a comparison between employment based analysis (EBA) and cost-benefit analysis

(CBA) on HC activity.

Even though operation models and techniques for MADA problem have been developed extensively, interdependency among criteria and alternatives may exist in real practice (Weber et al., 1990). An evaluation model with only top-down relationship or one-way loop form cannot appropriately represent the connections among the factors. As long as there is interrelationship among criteria and alternatives, the relationship should be shown as a network. Thus, the ANP (Saaty, 1996), which aims to tackle network problems, is adopted in this research to solve the interdependency problem of SD in collective residence environment.

3. Methodologies

3.1 Fuzzy Delphi Method (FDM)

To deal with the uncertainty of experts' subjective opinions effectively, Murray et al. (1985) first applied the fuzzy theory to the traditional Delphi Method. Ishikawa et al. (1993) employed the cumulative frequency distribution function and the fuzzy integration to integrate experts' estimation into fuzzy numbers, and utilized the "gray zone", the intersection of the fuzzy numbers, to develop the Max-Min FDM and the FDM via Fuzzy Integration (FDMFI).

Thereafter, Chang et al. (1995) and Chang & Wang (2006) extended the fuzzy number to the triangular fuzzy numbers (TFNs) to acquire the similarity degree among tolerable scope to select the critical factors from a list of possible factors. Moreover, Cheng (2001) and Hsiao (2006), based on Ishikawa et al. (1993), used TFNs to combine experts' cognitions and applied gray zone test to examine whether the cognitions has reached convergence. Zheng (2001), by revising the method of Cheng (2001), employed the geometric mean of experts' judgment to express the two TFNs for integrating comments and did the gray zone test. This paper bases on Zheng (2001) and the above some related researches, to find the critical factors. The proposed procedure is as follows:

Step 1: Collect all possible impact factors (PIFs) u_i . $U=\{u_i, i=1,2,\ldots,n\}$.

Step 2: Collect estimated score of each factor from each expert. The score is denoted as S^i by K experts; $S^i = \left(C_k^i, O_k^i\right), i=1,2,\ldots,$ n; $k=1,2,\ldots,$ K . C_k^i (O_k^i) is the lowest (highest) score of the *k*th expert to the *i*th factor, and both C_k^i and O_k^i have a range from 1 to 10 (Zheng, 2001).

Step 3: Calculate the minimum C_L^i *(*O_L^i*), the geometric mean (GM)* C_M^i *(*O_M^i*) and the maximum* C_U^i *(*O_U^i*) values of* C_k^i *(*O_k^i*) for each factor.*

Step 4: Establish the TFNs. The most conservative cognition value of a TFN is $C^i = \left(C_L^i, C_M^i, C_U^i\right)$, and the most optimistic cognition value is $O^i = \left(O_L^i, O_M^i, O_U^i\right)$. The overlap section of the two TFNs is called the gray zone, as shown in Figure 1 (Cheng, 2001; Hsiao, 2006).

Step 5: Inspect the consensus among experts' opinions. The gray zone of each factor is used to calculate the "important degree of consensus" (G^i) by Equation (1).

$$G^i = \{Y \mid \mu_{F^i(x)}(Y)\} \quad (1)$$

(1) If there is no overlap between the two TFNs, this indicates that the experts' opinions possess consensus, and $G^i = (C_M^i + O_M^i)/2$ (Zheng, 2001).

(2) If there is overlap between the two TFNs (the gray zone (Z^i) exists): to compare the Z^i and M^i, where $Z^i = C_U^i - O_L^i$ and $M^i = O_M^i - C_M^i$, G^i is calculated by Equation (2) and Equation (3) (Zheng, 2001).

$$F^i(x_j) = \left\{ \int_x \left\{ min\left[C^i(x_j), O^i(x_j) \right] \right\} dx \right\}, \ j \in U \quad (2)$$

$$G^{i} = \left\{ x_j \,\middle|\, \max \mu_{F^i}(x_j) \right\},\ j \in U \tag{3}$$

Step 6: Extract critical factors from U*, compare* G^i *with the threshold value (S).* If $G^i \geq S$, select factor *i*; and if $G^i < S$, eliminate factor *i* (Chang et al., 1997; Zheng, 2001). In general, the threshold value is determined by decision makers subjectively (Chang et al., 1997).

3.2 Analytic Network Process (ANP)

The ANP is the generalization of the analytic hierarchy process (AHP) by replacing hierarchies with networks (Saaty, 1996) and allowing more complex interrelationships in a network system. The ANP has been widely used in multi-criteria decision making (MCDM) problems in various fields such as strategic decision, project selection, product planning (Chung et al. 2005a), and so on.

The structural difference between a hierarchy and a network is depicted in Figure 2, where a node represents a component with elements inside it and an arc denotes the interaction between two components (Karsak et al., 2002). The direction of an arc represents dependence between two components; a two-way arrow indicates interdependency between two components; and a loop shows the inner dependence of elements within a component (Saaty, 1996; Chung et al., 2005b).

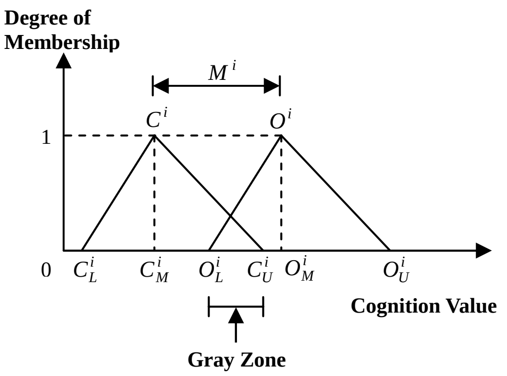

Figure 1. Two TFNs (Zheng, 2001)

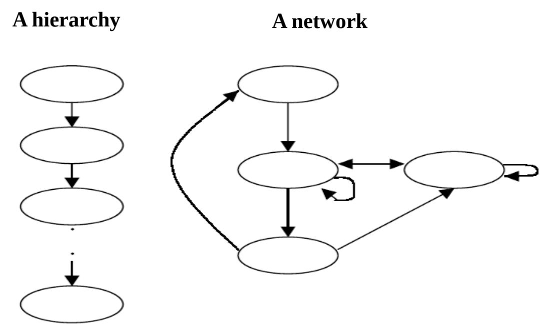

Figure 2. A hierarchy and a network (Chung et al., 2005b)

Saaty (1996) introduces the "supermatrix" to handle the interdependence characteristics, and a standard supermatrix form is as follows:

$$\mathbf{W} = \begin{array}{cc} & \begin{array}{ccccc} C_1 & \cdots & C_k & \cdots & C_N \\ e_{11}\cdots e_{1n_1} & \cdots & e_{k1}\cdots e_{kn_k} & \cdots & e_{N1}\cdots e_{Nn_N} \end{array} \\ \begin{array}{cc} C_1 & \begin{array}{c} e_{11} \\ \vdots \\ e_{1n_1} \end{array} \\ \vdots & \vdots \\ C_k & \begin{array}{c} e_{k1} \\ \vdots \\ e_{kn_k} \end{array} \\ \vdots & \vdots \\ C_N & \begin{array}{c} e_{N1} \\ \vdots \\ e_{Nn_N} \end{array} \end{array} & \begin{pmatrix} \mathbf{W}_{11} & \cdots & \mathbf{W}_{1k} & \cdots & \mathbf{W}_{1N} \\ \vdots & & \vdots & \ddots & \vdots \\ \mathbf{W}_{k1} & \cdots & \mathbf{W}_{kk} & \cdots & \mathbf{W}_{kN} \\ \vdots & & \vdots & \ddots & \vdots \\ \mathbf{W}_{N1} & \cdots & \mathbf{W}_{Nk} & \cdots & \mathbf{W}_{NN} \end{pmatrix} \end{array} \tag{4}$$

Let the components of a network system be C_k, $k = 1, . . . , N$, and let each component k has n_k elements, denoted by $e_{k1}, e_{k2}, \ldots, e_{kn_k}$. The influence of a set of elements belonging to a component on any element in another component can be represented as a priority matrix (W_{ij}) by applying pairwise comparisons in the same way as in the AHP. Wij shows the influence of the elements in the jth component to the elements in the ith component, and vice versa. In addition, if there is no influence, then $W_{ij} = 0$ (Huang et al., 2005; Chung et al., 2005b). The process of ANP is described as follows (Chung et al., 2005b; Saaty, 1996; Sarkis, 2003):

Step 1: Model construction and problem structuring. An example is shown in Figure 3. (Momoh & Zhu, 1998).

Step 2: Pairwise comparisons matrices and priority vectors. Like AHP, decision elements at each component are compared pairwisely with respect to their importance towards their control criterion, and the components themselves are also compared pairwisely with respect to their contribution to the goal (Chung et al., 2005b).

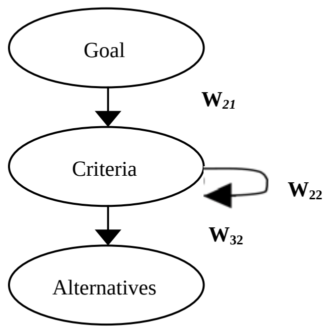

Figure 3. A network example(Momoh & Zhu, 1998)

Step 3: Supermatrix formation. To obtain global priorities in a system with interdependent influences, the obtained local priority vectors and matrices from *Step 2* are entered in a matrix to form a "supermatrix" as follows:

$$W = \begin{array}{r} \\ \textit{Goal} \\ \textit{Criteria} \\ \textit{Alternatives} \end{array} \begin{array}{c} \begin{array}{ccc} \textit{Goal} & \textit{Cri} & \textit{Alt} \end{array} \\ \begin{bmatrix} 0 & 0 & 0 \\ W_{21} & W_{22} & 0 \\ 0 & W_{32} & I \end{bmatrix} \end{array} \tag{5}$$

where "I" is the identity matrix, and entries of zeros correspond to those elements that have no influence. Next, in order to achieve a convergence on the importance weights, the supermatrix is raised to limiting powers by Equation (6) to obtain the limit matrix, which shows the global priority weights.

$$\lim_{k \to \infty} W^{2k+1} \tag{6}$$

Step 4: Selection of best alternatives. The priority weights of alternatives can be found in the column of alternatives in the normalized supermatrix (Sarkis, 2003; Chung et al., 2005b).

4. Evaluation Framework

4.1 Determination of Evaluating Criteria by FDM

In this research, nineteen experts from industry, government departments, and professional scholars from related area formed to contribute their expertise. Based on literature reviews, consideration of actual needs and characteristics of local area, we are able to list five major dimensions that influence SD of HC: (1) social level, (2) natural environment, (3) living use, (4) management and service, and (5) technology application. Moreover, 26 PIFs are generalized and categorized under the five dimensions (see Table 1).

TABLE 1. Dimensions and possible impact factors

Dimensions (Ds)	Possible impact factors (PIFs)
Social level (D_1)	Community ideology (F_1)
	Health (F_2)
	Safety (F_3)
	Culture education (F_4)
	Construction of style & features (F_5)
	Justice & opportunities (F_6)
	Properties of community constitution (F_7)
	Community connection (F_8)
Natural Environment (D_2)	Land use (F_9)
	Energy use (F_{10})
	Clean & recycling (F_{11})
	Preserve biodiversity (F_{12})
	Natural resources (F_{13})
	Pollution prevention (F_{14})
Living use (D_3)	Greenery open space (F_{15})
	Good dwellings & built environment (F_{16})
	Public facilities (F_{17})
	Satisfaction & comfort (F_{18})
	Traffic service system (F_{19})
Management and service (D_4)	Policies & ordinances (F_{20})
	Organizational operation (F_{21})
	Spontaneity management (F_{22})
	Effective guidance of government (F_{23})
Technology Application (D5)	Community network (F_{24})
	Security control system (F_{25})
	Digital life use (F_{26})

TABLE 2. Factor extraction results

PIFs	C_k^i		O_k^i		GMs		G^i
	Min	Max	Min	Max	C^i	O^i	
F_1	4	8	8	10	6.12	9.18	**7.65**
F_2	3	8	6	10	6.70	9.13	**7.41**
F_3	5	9	8	10	6.81	9.17	**8.35**
F_4	3	7	5	10	4.98	7.93	6.18
F_5	3	7	5	10	5.04	8.20	6.24
F_6	3	7	5	10	4.38	7.37	5.95
F_7	2	7	5	10	4.31	7.17	5.89
F_8	2	8	5	10	4.28	7.44	6.19
F_9	4	8	6	10	5.86	8.81	7.14
F_{10}	3	9	7	10	6.38	8.88	**7.84**
F_{11}	4	8	8	10	6.15	9.01	**7.58**
F_{12}	3	8	6	10	5.32	8.17	6.90
F_{13}	3	8	6	10	5.74	8.63	7.08
F_{14}	3	8	8	10	5.98	9.13	**7.55**
F_{15}	4	9	7	10	6.38	9.00	**7.87**
F_{16}	5	9	8	10	7.08	9.40	**8.42**
F_{17}	5	8	7	10	6.09	8.83	**7.49**
F_{18}	3	8	7	10	5.05	8.77	7.38
F_{19}	3	8	6	10	5.69	8.62	7.06
F_{20}	3	8	7	10	5.56	8.74	**7.42**
F_{21}	3	9	7	10	6.36	8.95	**7.85**
F_{22}	3	8	6	10	5.70	8.60	7.06
F_{23}	2	7	5	10	4.23	7.37	5.92
F_{24}	3	9	8	10	5.28	9.23	**8.25**
F_{25}	3	8	7	10	5.72	9.17	**7.49**
F_{26}	3	7	6	10	4.37	8.06	6.44
Numbers: 13 ($G^i \geq S$ (7.40), shown in gray)							

Next, FDM is applied to extract the factors from the PIFs. A convergence of experts' opinions is obtained, and 13 factors are extracted. In this research, we subjectively set 7.40 as the threshold value. The results are shown in Table 2, and the factors shaded in gray are selected.

4.2 Construction of Evaluation Model by ANP

With the results from FDM, a group meeting is carried out again to build up an evaluation model based on the ANP network structure proposed by Saaty (1996). In the process, the complete evaluation model is constructed as shown in Figure 4. In the evaluation model, the objectives and criteria correspond respectively to the 5 dimensions and 13 extracted factors from the FDM.

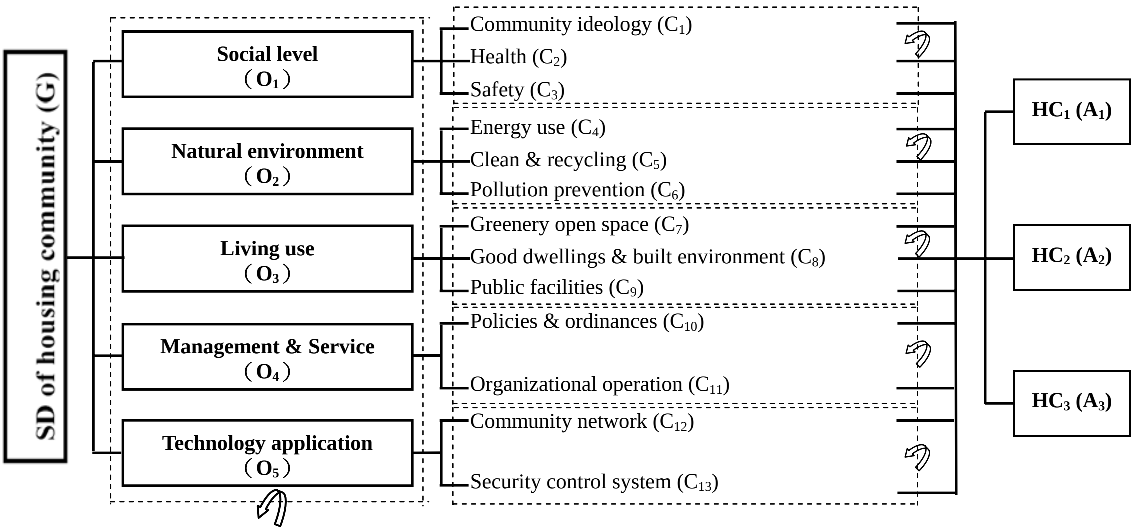

Figure 4. Evaluation model

Subsequently, the operational steps of ANP proceed based on the evaluation model. Three HCs (A_1, A_2, and A_3) are selected from Hsinchu area to examine the practicality of the proposed model. Seven experts are asked to fill out a set of pairwise comparison questionnaire. Based on the pairwise comparison results, priority/eigenvalue (EV) in each component and interdependencies in the model is calculated, and consistency (CR $\leq$ 0.1) is tested. Because there are numerous pairwise comparisons matrices (PCM), only partial calculation is illustrated (G-O_1-C_1-A) in Table 3.

Table 3. Representation of PCM

G	**O_1**	**O_2**	**O_3**	**O_4**	**O_5**	***EV***
O_1	1	3	2	4	6	**0.419**
O_2	1/3	1	1/2	2	3	**0.155**
O_3	1/2	2	1	4	5	**0.282**
O_4	1/4	1/2	1/4	1	2	**0.089**
O_5	1/6	1/3	1/5	1/2	1	**0.055**
						***CR*=0.014**

C_1	**C_1**	**C_2**	**C_3**	***EV***
C_1	1	5	3	**0.627**
C_2	1/5	1	1/4	**0.094**
C_3	1/3	4	1	**0.280**
				***CR*=0.074**

O_1	**C_1**	**C_2**	**C_3**	***EV***
C_1	1	6	2	**0.600**
C_2	1/6	1	1/3	**0.100**
C_3	1/2	3	1	**0.300**
				***CR*=0**

C_1	**A_1**	**A_2**	**A_3**	***EV***
A_1	1	2	1/4	**0.218**
A_2	1/2	1	1/3	**0.152**
A_3	4	3	1	**0.630**
				***CR*=0.093**

All the priorities calculated from the pairwise comparison matrices are entered in the initial supermatrix (see Table 4) using Equation (5). However, the supermatrix does not have column stochastic. Each block in that column is multiplied by 0.5 to make the column stochastic. By this way, a weighted supermatrix is formed. The weighted supermatrix is then raised to limiting powers by Equation (6) to capture all the interactions and to obtain the limit supermatrix (see Table 5). The alternative with the largest priority should have the best overall performance. The performance of the three alternatives is: A_3 (0.394) $\succ$ A_2 (0.324) $\succ$ A_1 (0.281).

Table 4. Initial supermatrix

	G	O_1	O_2	O_3	O_4	O_5	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	**A_1**	**A_2**	**A_3**
G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O_1	0.419	0.475	0.304	0.103	0.318	0.230	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O_2	0.155	0.072	0.489	0.062	0.159	0.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O_3	0.282	0.122	0.070	0.295	0.045	0.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O_4	0.089	0.287	0.137	0.540	0.392	0.122	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O_5	0.055	0.045	0.000	0.000	0.086	0.648	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_1	0	0.600	0	0	0	0	0.627	0.582	0.230	0	0	0	0	0	0	0	0	0	0	0	0	0
C_2	0	0.100	0	0	0	0	0.094	0.110	0.122	0	0	0	0	0	0	0	0	0	0	0	0	0
C_3	0	0.300	0	0	0	0	0.280	0.309	0.648	0	0	0	0	0	0	0	0	0	0	0	0	0
C_4	0	0	0.648	0	0	0	0	0	0	0.540	0.300	0.128	0	0	0	0	0	0	0	0	0	0
C_5	0	0	0.230	0	0	0	0	0	0	0.297	0.600	0.276	0	0	0	0	0	0	0	0	0	0
C_6	0	0	0.122	0	0	0	0	0	0	0.163	0.100	0.595	0	0	0	0	0	0	0	0	0	0
C_7	0	0	0	0.258	0	0	0	0	0	0	0	0	0.540	0.239	0.111	0	0	0	0	0	0	0
C_8	0	0	0	0.637	0	0	0	0	0	0	0	0	0.297	0.625	0.222	0	0	0	0	0	0	0
C_9	0	0	0	0.105	0	0	0	0	0	0	0	0	0.163	0.137	0.667	0	0	0	0	0	0	0
C_{10}	0	0	0	0	0.333	0	0	0	0	0	0	0	0	0	0	0.750	0.667	0	0	0	0	0
C_{11}	0	0	0	0	0.667	0	0	0	0	0	0	0	0	0	0	0.250	0.333	0	0	0	0	0
C_{12}	0	0	0	0	0	0.143	0	0	0	0	0	0	0	0	0	0	0	0.200	0.333	0	0	0
C_{13}	0	0	0	0	0	0.857	0	0	0	0	0	0	0	0	0	0	0	0.800	0.667	0	0	0
A_1	0	0	0	0	0	0	0.218	0.137	0.701	0.726	0.122	0.122	0.082	0.070	0.162	0.100	0.096	0.098	0.648	1	0	0
A_2	0	0	0	0	0	0	0.152	0.239	0.193	0.172	0.230	0.230	0.603	0.604	0.770	0.600	0.210	0.187	0.230	0	1	0
A_3	0	0	0	0	0	0	0.630	0.625	0.106	0.102	0.648	0.648	0.315	0.326	0.068	0.300	0.694	0.715	0.122	0	0	1
SUM	1.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	1	1	1

5. Results and conclusions

This research combines the FDM and the ANP to develop an evaluation model for SD of collective residence environment. The results of this research are briefly listed here.

First, through the process of FDM, a large number of abstract, qualitative and sensational PIFs are effectively extracted into a limited number of representative evaluation criteria. In this research, 26 initial PIFs are extracted into 13 criteria.

Table 5. The limit supermatrix

	G	O_1	O_2	O_3	O_4	O_5	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	**A_1**	**A_2**	**A_3**
G	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
O_1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
O_2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
O_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
O_4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
O_5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C_1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C_2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C_4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C_5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C_6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C_7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C_8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C_9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C_{10}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C_{11}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C_{12}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C_{13}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A_1	**0.281**	0.330	0.380	0.147	0.193	0.462	0.298	0.261	0.593	0.562	0.221	0.182	0.089	0.080	0.142	0.099	0.097	0.304	0.562	1.000	0.000	0.000
A_2	**0.324**	0.240	0.236	0.506	0.355	0.236	0.163	0.207	0.189	0.188	0.220	0.224	0.621	0.620	0.733	0.549	0.346	0.203	0.223	0.000	1.000	0.000
A_3	**0.394**	0.430	0.384	0.347	0.453	0.302	0.540	0.532	0.218	0.250	0.559	0.594	0.291	0.300	0.125	0.351	0.557	0.493	0.215	0.000	0.000	1.000

Second, the ANP is adopted to further analyze the results from the FDM. With a network structure, the method systematically reflects the interdependence existing in each evaluation components and calculates the importance of components and alternatives through objective mathematical matrix manipulation. The outcome of the evaluation network model displays the interdependence among the five objectives and inner dependence in each criteria cluster. Furthermore, the model can calculate the ranking of the three HCs under the main goal (HC_3 (0.394) $\succ$ HC_2 (0.324) $\succ$ HC_1 (0.281)), and also the performances of each HC under each objective or under each criterion. These outcomes recommend a developing direction toward SD for each HC under the study.

To sum up, this paper sets up a network evaluation model, which can transform the abstract concept of SD into an applicable approach. Subjective qualitative characteristics and needs in local HC can be converted into objective numerical weights for reference. In addition, the model is theoretical correct and easy to operate. The results from this research not only can be fundamental reference for future development application, but also can be guidelines for project planning and development in practice. Furthermore, the results can be useful references for relevant policy making in public sectors.

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計畫成果自評

一.研究內容與原計畫之相符程度

本計畫目的在於建立起系統性的客觀評價模式，過程中除探討Fuzzy Delphi method (FDM) 與Analytic network process (ANP) 方法的理論、操作流程與數學演算外，更透過相關領域專家學者的觀點予以串連整合、並利用地區實際案例加以實證；整體研究內容完全與原始計畫及目標相契合。

二.預期成果達成狀況

(一)評價準則的建立：透過Fuzzy Delphi method將相關文獻研究、地區特質與需求、以及專家學者觀點有效整合，客觀地建構出確切、且可真實反映實際需求的十三項評價準則。

(二)整體評價模式的建構：藉由Analytic network process方法適切地承續既以建立之評價準則，並有效處理問題間可能存在的相互依存關係，明確地建構出一能將偏屬質性、主觀認知的問題，轉化為量化、客觀表示的評價模式(Evaluation Model)。

(三)評價模式的實證：應用於地區實際案例的操作，可藉由各案例於評價目標與各準則之權重數值的表示，分別明確地評比出案例間發展狀況的優劣順序、以及各案例於評價模式中所有組成元素之現況反映。成果可供個案擬定強化方向與改善策略之明確參考。

三.研究成果之貢獻

(一)評價模式可為各領域於相關分析、評價、決策…等問題之解決，提供一客觀、適切且具可操作性的依循。

(二)整體結果除可為現行住宅社區之發展提供檢討、研擬可行發展策略外，尚可提供予政府公部門、以及相關規劃設計單位於政策研擬與落實發展時之參考基礎。

四.研究成果之發表

本計畫之相關成果已發表至國際研討會（2007 APMC，2008 BAI）兩篇、並已投稿至SCI之國際期刊（Expert Systems With Applications）一篇，詳列如下：

(一)國際研討會

1. **<u>Wei-Ming Wang</u>**, Ding-Tsair Chang, and Amy H. I. Lee, (2007). Preliminary Evaluation Modeling for Sustainable Development of Collective Residence Environment: Scope in Taiwan's Housing Community. *The 13th Asia Pacific Management Conference*, November 18-20, 2007, pp. 743-752, Melbourne, Australia.

2.**<u>Wei-Ming Wang</u>**, (2008). MCDM Applied to the Assessment of Sustainable Development for Taiwan's Collective Residence Environment. *2008 International Conference on Business and Information*, July 7-9, 2008, Disc pp. 1-12, Seoul, South Korea.

(二)國際期刊

1.**<u>Wei-Ming Wang</u>**, Amy H. I. Lee, and Ding-Tsair Chang, (2008). An Integrated FDM-ANP Approach for Evaluating Sustainable Development of Taiwan's Collective Residence Environment. Expert Systems With Applications. pp. 1-29. (SCI; 2008.08.06 投稿，審稿中).

附件一

行政院國家科學委員會補助國內專家學者出席國際學術會議報告

97 年 **7** 月 **21** 日

報告人姓名	**王　維　民**	服務機構及職稱	**中華大學 建築與都市計畫學系 講師**
會議時間地點	**97.07.07.～97.07.09. Seoul, South Korea**	本會核定補助文號	**臺會綜二字第 0960033672 號 (96.07.11.) (NSC 96-2415-H-216-005-SSS)**
會議名稱	(中文) (英文) **International Conference on Business And Information 2008**		
發表論文題目	(中文) (英文) **MCDM APPLIED TO THE ASSESSMENT OF SUSTAINABLE DEVELOPMENT FOR TAIWAN'S COLLECTIVE RESIDENCE ENVIRONMENT**		

報告內容應包括下列各項：

一、參加會議經過

本人於 7 月 6 日搭乘華航 CI160 班機抵達 South Korea，參加 7 月 7 日至 7 月 9 日由 Academy of Taiwan Information Systems Research 於 Seoul city " JW Marriott Hotel Seoul" 所舉行的 "the 2008 International Conference on Business and Information" (The BAI 2008 Conference)國際研討會。

該項研討會，本年度徵文共區分 "Management Information System" **…**等 24 項主題，合計有來自五大洲 39 個國家、700 篇學術論文投稿；文稿經審查後有 465 篇得於本次會議議程中分派於 A1～G7 等 53 個不同場次進行發表。本人所發表之 **"**MCDM APPLIED TO THE ASSESSMENT OF SUSTAINABLE DEVELOPMENT FOR TAIWAN'S COLLECTIVE RESIDENCE ENVIRONMENT**"** 論文，投稿於 "Social Issues in Management" 主題，並被安排於〔A5〕場次之第 1 順位發表。該場次主持人由菲律賓 Far Eastern 大學 Peithe Ma Salva 教授擔任，並安排有 6 篇學術論文，全數皆由第一作者之教授、學者親自解說，有機會參與並聆聽多位國際學者之精闢發表，實為難得。

本人論文係針對集居環境因應全球永續發展（Sustainable Development）)之思潮與趨勢，反省於台灣集居環境的發展與管理已由對「量」的基本滿足轉型於對「質」的需求提升，亟需在「全球思考、地方行動」的行動概念下，透過對地區發展特性與需求之掌握、落實永續之對應單元的釐清（即「集合住宅社區」)，建立起客觀、可量化且具可操作性的評價模式（Evaluation Model）。當報告結束時，隨即引起在座與會學者之興趣而加以提問與討論；而，其中多數皆關注於本研究之能將質性、主觀的問題轉換為量化、客觀的實質評價操作。此外，除了自身發表場次外，尚且依議程場次表所列，選擇參與部分場次，除瞭解現下國際間於相關領域研究之趨勢與重點外、並吸收、學習相關研究上的新穎觀念與研究方法。

二、與會心得

透過本次國際研討會的論文發表及參與，由於能引起他國學者之興趣與關注，足以印證在整體研究之設定與成果上極具發展性，給予自我極大的鼓勵與信心強化。

而，藉由此次的會議參與，由於能廣泛地接觸到其他不同專業領域的研究、與學者們新穎的思維與論點，除可有效拓展視野、增強見聞外，對於未來研究領域上議題的發掘與設定、以及方法的適切引用有著莫大的啟發與幫助。此外，發現有諸多的研究成果係透過跨領域的結合與運作，而產生有別於傳統單一研究領域思維模式之創新，甚具開創性與研究競爭力。此一現象未來應將是個人研究方向之設定、與所屬學校提升整體學術研究特色可留意之重點。

三、考察參觀活動(無是項活動者省略)

四、建議

該研討會由 Academy of Taiwan Information Systems Research (ATISR)所主辦，此為台灣學術團體協會，近年來相繼於亞洲主要國家之首都城市舉行；由於鼓勵跨領域研究之整合，吸引國際間參與之國家與投稿件數極具規模，已成為國際頗具知名之學術盛會，而具有一定程度之學術國際能見度。是以，建議國家級之學術領導單位若能與此類似層級之國際研討會相結合，以其既已建立之成果為基礎，將可快速且有效地宣傳台灣學術研究之能量、並可加以連結與拓展相關之國際性合作與地位。

五、攜回資料名稱及內容

(一)Proceedings of Business And Information 2008 (ISSN:1729-9322)（乙本）

(二)論文光碟（乙片）

(三) Contemporary Management Research Vol.4, No.1 March 2008 (ISSN:1813-5498) (乙本）

(四) Contemporary Management Research Vol.4, No.2 June 2008 (ISSN:1813-5498) (乙本）

(五) International Journal of BUSINESS & INFORMATION Vol.2, No.1 June 2007 (ISSN:1728-8673) (乙本）

(六) International Journal of Cyber Society and Education Vol.1, No.1 March 2008 (ISSN:1995-6649) (乙本）

六、其他

附件二

MCDM APPLIED TO THE ASSESSMENT OF SUSTAINABLE DEVELOPMENT FOR TAIWAN'S COLLECTIVE RESIDENCE ENVIRONMENT

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ABSTRACT

When sustainable development (SD) becomes the global trend on collective residence environment, it needs to transform the abstract concept into specific and practicable implementations. Hence, the correspondent of the concept to geographical space must be distinguished first, and the objective evaluation method on regional property must be developed next. The major type of Taiwan's dwelling is housing with high-rise, high density and centralization. Besides, urbanization has pushed traditional "community" into "housing community", which emphasizes the satisfaction of personal living quality, privacy and safety. For implementing SD effectively, this paper first searches the relevant possible impact factors. Moreover, the characteristics of location development and dwellers' actual demand are integrated by the fuzzy Delphi method (FDM) to extract the aspects and criteria for assessment. Since there is complex interdependence among assessment aspects/criteria, the analytic network process (ANP) method, which can solve such multi-criteria decision making (MCDM) problem effectively, is employed. The series of operations can transfer the subjective and qualitative perception problems into the objective and quantitative evaluation achievements. The results can be not only the foundation to implement the sustainable conception, but also the consultation and guidance for planning and practicing in the future.

Keyword: Sustainable Development, Housing Community, Fuzzy Delphi Method, Analytic Network Process

INTRODUCTION

With swift changing in time, industrialization reduces the dependence of people on community. Convenient transportation under urbanization also lengthens the distance between working location and residence. Frequent communication and network cooperation in globalization collapse the pattern of living interaction (Birkeland, 2002). These trends change the living style from the traditional community with characteristics of social interaction, shared ties and geographical location (Hillery, 1955) to self-satisfaction, privacy, and an emphasis on occupational interest than community interest, and gradually to an isolated and sterile accommodation (Churchill & Baetz, 1999; Schneider, 1992; Wight, 1995).

Since 1980s, sustainable development (SD) has emerged as a popular solution to the problem of meeting the material needs of a rapidly growing population (Bridger & Luloff, 1999). Many scholars attempt to apply sustainability to the issues of residence community (Barton, 2000; Bridger & Luloff, 1999; Chan & Huang, 2004; Lafferty, 2002; Paterson & Connery, 1997; Weber, 2003). Based on the environment, social and economy impacts that were emphasized in the 1996 Habitat II Conference, many research works have explored the restriction and utilization of resources and ecology, the living attitude (style) and needs (quality) of residents, and the policies and management in operation and development. As a result, concepts, such as "green community" (Lin & Lee, 2005; Young, Makoni, & Christiansen, 2001), "ecology community" (O'Hara & Stagl, 2002; Roseland, 1997; Zhang & Shyng, 2004) and "healthy community" (Farmer, Lauder, Richards, & Sharkey, 2003; Raphael, Renwick, Brown, Steinmetz, Sehdev, & Phillips, 2001), are developed.

When the trend of development and management of human residence environment becomes focusing on the concept of SD over the world, the abstract concept of "thinking globally, action locally" needs to be transferred into specific and practicable approach. Implementation of SD effectively in residence environment should have two structural concerns. First, the appropriate space of geographical scale for action should be included. Second, an objective and valid measurement method should be developed (Chan & Huang, 2004; Chan & Wu, 2003).

Due to the limitation of land and condensed population in Taiwan, housing community designed with collective dwelling type has become a basic construction unit in residential environment and urban development. Furthermore, the government should define residence and community clearly for moving toward SD under rapid transition based on highly urbanization, industrialization and technology (National Council for Sustainable Development, 2000). That is to say, housing community is the corresponding to space of geographical scale for action as well as the foundation to extend overall development (Chan & Wu, 2003).

A number of studies (Frasera, Dougilla, Mabeeb, Reeda, & Alpinec, 2006; Maclaren, 1996; Spangenberg, Pfahl, & Deller, 2002; UNSDC, 1997) have shown that the establishment of evaluating indicators/criteria is an essential work for effectively transferring the concept into developing space units. Evaluation model can then be developed (e.g. Deakin, 2003; Lin & Lee, 2005; Yuan, James, Hodgson, Hutchinson, & Shi, 2003). Nevertheless, in the process of operating performance model, there are complicated interrelationships existing among various factors (Chan & Huang, 2004; Maclaren, 1996). Such a characteristic belongs to multi-attribute decision analysis (MADA). Many works done on MADA (Chen, Li, & Wong, 2005; Lee & Kim, 2001; Lee & Li, 2006; Sarkis, 2003) showed that the fuzzy Delphi method (FDM) can extract definite factors effectively from related attributes. The extracted factors can then be criteria for measurement. In addition, the analytic network process (ANP) has the ability to handle interdependency among attributes and criteria. It can also transform subjective and qualitative issues into an objective and quantitative model for evaluation (Meade & Presley, 2002).

The purpose of this paper is to establish an explicit, objective and applicable evaluation model that transforms abstract SD concept based on characteristics and requirements of local basic unit. The results shall show that the quantitative weights of each component in the model are objective in nature. When the alternatives are added into the evaluation model, it could examine the implementation of the SD concept more specifically and practically. Moreover, it will also offer sufficient planning and executing guidance to overall local residential environment development in the future.

EXISTED EVALUATION MODELS AND METHODS

From literature review, we can understand that there are extensive influencing dimensions and attributes for housing community SD. Thus, when engaging measurement and evaluation, this is a MADA problem. In general, a MADA problem must have a simple but clear goal as well as objectives and/or criteria connecting under the goal. There were numerous methods conducted in the past, such as ranking technique (Buss, 1983), scoring (Lucas & Moor, 1976), AHP (Muralidhar & Santhnanm, 1990), multivariable analysis method, and mathematical models including goal programming, dynamic programming, zero-one goal programming and so on (Nemhauser & Ullman, 1969; Reiter & Rice, 1966; Roper-Low & Sharp, 1990; Saaty, 1996; Sanathanam & Kyparisis, 1996; Santhanam, Muralidhar, & Schniederjans, 1989). The above methodologies can deal with simple and simplified thinking models. However, to solve the complex interrelationship among factors for the abstract SD concept, the above techniques are not adequate enough. Therefore, in recent years, a few works have been undertaking on this topic using various methods or models.

Most of the measuring approaches and evaluation models focusing on this field tried to establish influencing factors, indicators or criteria first (Andrew & Carroll, 2001; Bell & Morse, 2004). Reed, Fraser & Dougill (2006) set up a learning process by integrating approaches of top-down from expert-led and bottom-up from community-based. It is the foundation for local sustainability evaluation criteria which are stakeholder-led oriented. The criteria and SD goal of housing community form a loop structure, and community-driven participatory methods (CDPM) is adopted for evaluation. Chan & Hung (2004) considered variables for community development and set up influencing factors, and then engaged in systematic evaluation research by sensitivity model (SM). Moreover, Taylor (2001) made a comparison between employment based analysis (EBA) and cost-benefit analysis (CBA) on housing community activity.

Even though operation models and techniques for MADA problem have been developed extensively, interdependency among criteria and alternatives may exist in real practice (Weber, Werners & Zimmerman, 1990). An evaluation model with only top-down relationship or one-way loop form cannot appropriately represent the connections among the factors. As long as there is interrelationship among criteria and alternatives, the relationship should be shown as a network. Thus, the ANP (Saaty, 1996), which aims to tackle network problems, is adopted in this research to solve the interdependency problem of SD in collective residence environment.

FRAMEWORK AND METHODS

The framework of this paper consists of several parts as shown in Figure 1. First, related aspects and attributes for SD of residential/housing community are identified through relevant literature review and local characteristics. The critical evaluation criteria are determined by the FDM next. After constructing the evaluation network model by the experts' group discussion, we can calculate the priorities/weights of critical criteria by applying the ANP method. The final ranking results of the empirical case for housing community SD are obtained. The detailed descriptions of each part of the framework are presented in the following sub-sections.

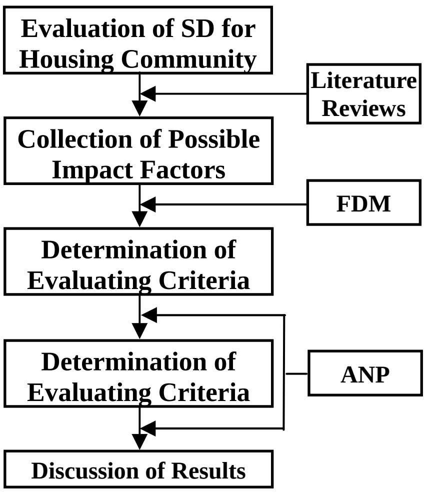

FIGURE 1. Research Framework

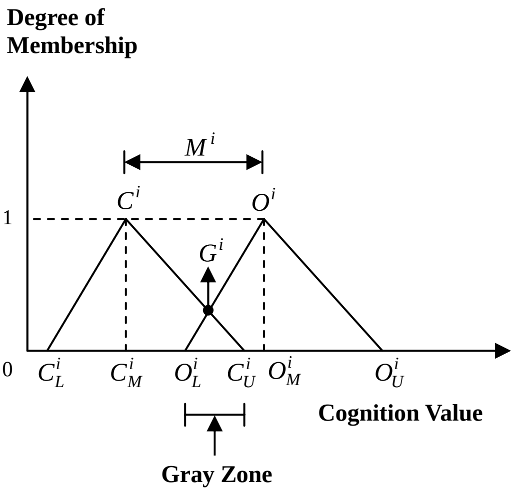

FIGURE 2. Two TFNs (Zheng, 2001)

Fuzzy Delphi Method (FDM)

To deal with the uncertainty of experts' subjective opinions effectively, Murray, Pipino, & Van Gigch (1985) first applied the fuzzy theory to the traditional Delphi Method. Ishikawa, Amagasa, Shiga, Tomizawa, Tatsuta, & Mieno (1993) employed the cumulative frequency distribution function and the fuzzy integration to integrate experts' estimation into fuzzy numbers, and utilized the "gray zone", the intersection of the fuzzy numbers, to develop the Max-Min FDM and the FDM via Fuzzy Integration (FDMFI). Other works on FDM include Chang, Tsujimura, Gen & Tozawa (1995), Chang & Wang (2006), Cheng (2001), Hsiao (2006), Wang, Chang, & Lee (2007) and Zheng (2001).

This paper bases on the FDM developed by Ishikawa et al. (1993) and Zheng (2001) to find the critical factors. The proposed procedure is as follows (Wang et al., 2007):

Step 1: ***Collect all possible factors u_i.***

Step 2: ***Collect estimated score of each factor (u_i) from each expert.*** The score is denoted as S_i by k experts, $S_i = \{(C_{ik}, O_{ik})\}$. C_{ik} is the lowest score of the ***kth*** expert to the ***ith*** factor,; O_{ik} is the highest score, and both C_{ik} and O_{ik} have a range from 1 to 10 (Chang & Wang, 2006; Zheng, 2001).

Step 3: ***Calculate the extreme values of C_{ik} and O_{ik} for each factor.*** A group average is calculated for both C_{ik} and O_{ik}, and calculate the minimum C_L^i (O_L^i), the geometric mean (GM) C_M^i (O_M^i) and the maximum C_U^i (O_U^i) of C_k^i (O_k^i).

Step 4: ***Establish the TFNs.*** There are two TFNs: denoted as $C^i = (C_L^i, C_M^i, C_U^i)$ and $O^i = (O_L^i, O_M^i, O_U^i)$. The overlap section of the two TFNs is called the gray zone, as shown in Figure 2 (Zheng, 2001).

Step 5: ***Inspect the consensus among experts' opinions***. The gray zone of each factor is used to calculate the "important degree of consensus" (G^i), and the higher value of G^i, the higher significance of u_i.

(1) **If there is no overlap between the two TFNs ($C_U^i \leq O_L^i$)**,this indicates that the experts' opinions possess consensus (Zheng, 2001), and $G^i = (C_M^i + O_M^i)/2$.

(2) **If there is overlap ($C_U^i > O_L^i$), the gray zone (Z^i) exists:**

(a) If $Z^i < M^i$, where $Z^i = C_U^i - O_L^i$ and $M^i = O_M^i - C_M^i$, G^i is calculated by Equation (1) and Equation (2).

$$F^i(x_j) = \left\{ \int_x \left\{ \min\left[C^i(x_j), O^i(x_j) \right] \right\} dx \right\}, i \in U \quad (1)$$

$$G^i = \left\{ Y \mid \max \mu_{F^i}(Y) \right\}, i \in U \quad (2)$$

(b) If $Z^i > M^i$, there are discrepancies among the experts' opinions. Repeat Step 2 to Step 5 until a convergence is attained.

Step 6: ***Extract critical factors from U, compare G^i with the threshold value (S).*** If $G^i \geqq S$, select factor i; and if $G^i < S$, eliminate factor i (Zheng, 2001). In general, the threshold value is determined by decision makers subjectively (Chang, Hsu, & Chen, 1997).

Analytic Network Process (ANP)

The ANP is the generalization of the analytic hierarchy process (AHP) by replacing hierarchies with networks (Saaty, 1980, 1996, 2005) and allowing more complex interrelationships in a network system. The ANP has been widely used in multi-criteria decision making problems in various fields such as strategic decision (Raisinghani & Meade, 2005; Sarkis, 2003), project selection (Eddie & Li, 2005; Meade & Presley, 2002), product planning (Chen et al., 2005; Chung, Lee, & Pearn, 2005a), and so on.

The process of ANP is described as follows (Chung et al., 2005a; Saaty, 1996; Wang et al., 2007) :

Step 1: ***Model construction and problem structuring.*** The problem should be stated clearly and decomposed into a rational system like a network, which would indicate the relationship of feedback or interdependence among the components, by decision makers.

Step 2: ***Pairwise comparisons matrices and priority vectors.*** Like AHP, decision elements at each component are compared pairwisely with respect to their importance towards their control criterion, and the components themselves are also compared pairwisely with respect to their contribution to the goal (Chung , Lee, & Pearn, 2005b). The relative importance values are determined with a scale of 1 to 9, and an eigenvector can be obtained.

Step 3: ***Supermatrix formation.*** To obtain global priorities in a system with interdependent influences, the obtained local priority vectors and matrices from Step 2 are entered in a matrix to form a "supermatrix" as follows:

$$\mathbf{W} = \begin{array}{r} \\ \textit{Goal} \\ \textit{Criteria} \\ \textit{Alternatives} \end{array} \begin{array}{c} \begin{array}{ccc} \textit{Goal} & \textit{Cri} & \textit{Alt} \end{array} \\ \begin{bmatrix} \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{w_{21}} & \mathbf{w_{22}} & \mathbf{0} \\ \mathbf{0} & \mathbf{w_{32}} & \mathbf{I} \end{bmatrix} \end{array} \tag{3}$$

where "I" is the identity matrix, and entries of zeros correspond to those elements that have no influence. After forming the supermatrix, a weighted supermatrix is derived by transforming all columns sum to unity; i.e. like the concept of Markov chain for ensuring the column stochastic equals to 1 (Huang, Tzeng, & Ong, 2005). Next, in order to achieve a convergence on the importance weights (Huang et al., 2005), the weighted supermatrix is raised to limiting powers by Equation (4) to obtain the limit matrix, which shows the long-term stable weighted values (Chung et al., 2005a) and the global priority weights. The detail of mathematical processes of the ANP approach can refer to Saaty (1996).

$$\lim_{k \to \infty} \mathbf{W}^{2k+1} \tag{4}$$

Step 4: ***Selection of best alternatives***. If the supermatrix formed in Step 3 covers the whole network, the priority weights of alternatives can be found in the column of alternatives in the normalized supermatrix (Chung et al., 2005b, Sarkis, 2003).

EVALUATION FRAMEWORK

Determination of Evaluating Criteria by FDM

In this research, a committee with experts from industry, government departments, and professional scholars from related area is formed to contribute their expertise in sustainable development of collective residence environment. Based on literature reviews, consideration of actual needs and characteristics of local area, and the results of the first group discussion of the committee, we are able to list five major dimensions that influence SD of housing community: (1) social level, (2) natural environment, (3) living use, (4) management and service, and (5) technology application. Moreover, 26 possible impact factors are generalized and categorized under the five dimensions. The five dimensions and their possible impact factors are listed in Table 1 (Huang & Wang, 2006; Wang et al., 2007).

Next, FDM is applied to extract the factors from the possible impact factors. An anonymous questionnaire is prepared to let the committee members evaluate the importance of each possible impact factor. A convergence of their opinions is obtained, and 13 factors are extracted. In this research, we subjectively set 7.40 as the threshold for the geometric mean of experts' consensus value (G^i). The results are shown in Table 2 (Huang & Wang, 2006; Wang et al., 2007), and the factors shaded in gray are selected.

Construction of Evaluation Model by ANP

With the results from FDM, a group discussion of experts is carried out again to build up an evaluation model based on the ANP network structure proposed by Saaty (1996). In the process, experts agree that there is certain interdependence and feedback among the goal, objectives and criteria and that alternatives (different housing communities) should be evaluated in the network. The committee reaches a consensus that there is interdependence among the dimensions, and the factors under different dimensions (clusters) have interdependence too. However, the interdependence of the dimensions has adequately captured the interdependence of the factors under different dimensions (clusters). As a result, we can assume an independency of the factors under different dimensions (clusters), and thus only study the interdependence among the factors under the same dimension. The complete evaluation model is constructed as shown in Figure 3. In the evaluation model, the objectives and criteria correspond respectively to the five dimensions and 13 extracted factors from the FDM in the previous sub-section.

TABLE 1. Dimensions and possible impact factors

Dimensions (Ds)	Possible impact factors (PIFs)
Social level (D_1)	Community ideology (F_1)
	Health (F_2)
	Safety (F_3)
	Culture education (F_4)
	Construction of style & features (F_5)
	Justice & opportunities (F_6)
	Properties of community constitution (F_7)
	Community connection (F_8)
Natural Environment (D_2)	Land use (F_9)
	Energy use (F_{10})
	Clean & recycling (F_{11})
	Preserve biodiversity (F_{12})
	Natural resources (F_{13})
	Pollution prevention (F_{14})
Living use (D_3)	Greenery open space (F_{15})
	Good dwellings & built environment (F_{16})
	Public facilities (F_{17})
	Satisfaction & comfort (F_{18})
	Traffic service system (F_{19})
Management and service (D_4)	Policies & ordinances (F_{20})
	Organizational operation (F_{21})
	Spontaneity management (F_{22})
	Effective guidance of government (F_{23})
Technology Application (D5)	Community network (F_{24})
	Security control system (F_{25})
	Digital life use (F_{26})

TABLE 2. Factor extraction results

PIFs	C_{ik}		O_{ik}		GMs		G^i
	Min	Max	Min	Max	C_i	O_i	
F_1	4	8	8	10	6.12	9.18	**7.65**
F_2	3	8	6	10	6.70	9.13	**7.41**
F_3	5	9	8	10	6.81	9.17	**8.35**
F_4	3	7	5	10	4.98	7.93	6.18
F_5	3	7	5	10	5.04	8.20	6.24
F_6	3	7	5	10	4.38	7.37	5.95
F_7	2	7	5	10	4.31	7.17	5.89
F_8	2	8	5	10	4.28	7.44	6.19
F_9	4	8	6	10	5.86	8.81	7.14
F_{10}	3	9	7	10	6.38	8.88	**7.84**
F_{11}	4	8	8	10	6.15	9.01	**7.58**
F_{12}	3	8	6	10	5.32	8.17	6.90
F_{13}	3	8	6	10	5.74	8.63	7.08
F_{14}	3	8	8	10	5.98	9.13	**7.56**
F_{15}	4	9	7	10	6.38	9.00	**7.87**
F_{16}	5	9	8	10	7.08	9.40	**8.42**
F_{17}	5	8	7	10	6.09	8.83	**7.49**
F_{18}	3	8	7	10	5.05	8.77	7.38
F_{19}	3	8	6	10	5.69	8.62	7.06
F_{20}	3	8	7	10	5.56	8.74	**7.42**
F_{21}	3	9	7	10	6.36	8.95	**7.85**
F_{22}	3	8	6	10	5.70	8.60	7.06
F_{23}	2	7	5	10	4.23	7.37	5.92
F_{24}	3	9	8	10	5.24	9.24	**8.25**
F_{25}	3	8	7	10	5.76	9.13	**7.49**
F_{26}	3	7	6	10	4.39	8.01	6.44
Numbers: 13 ($G^i \geq S$ (7.40), shown in gray)							

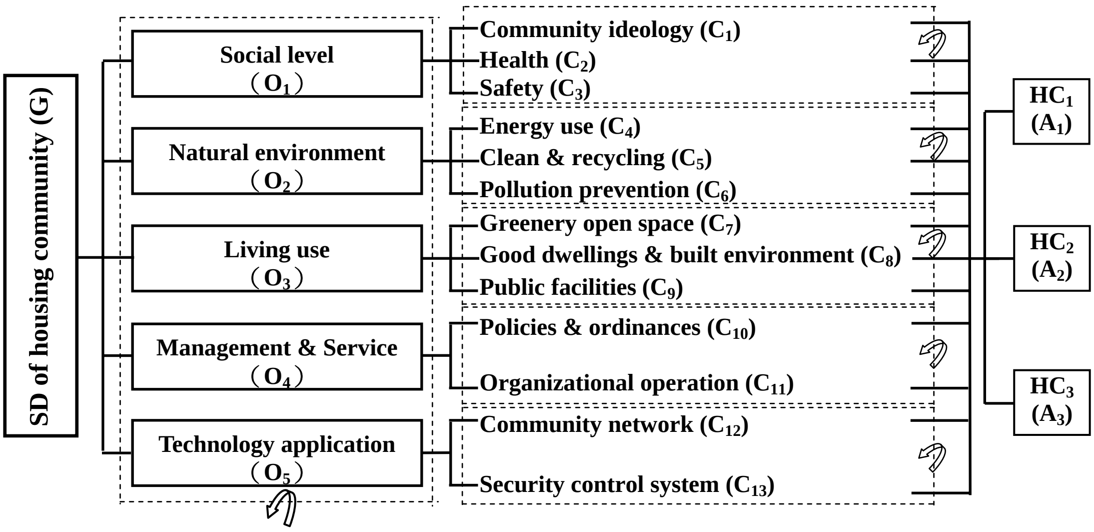

FIGURE 3. Evaluation model

Subsequently, the operational steps of ANP proceed based on the evaluation model. Three housing communities (represented as A_1, A_2, and A_3) are selected from Hsinchu area to examine the practicality of the proposed model. The requirements of housing community under the study are as follows: building construction completed in the last 5 years, well developed, fully residential occupied, similar scale and characteristics, and maintained by community/property management agents. Experts, including professionals with the specialty of architecture design, urban planning, community management, and government official and familiar with the management of the three communities, are asked to discuss and fill out a set of pairwise comparison questionnaire. Then, based on the comparison results, priority/eigenvalue (EV) in each component and interdependencies in the model is calculated, and consistency ($CR \leq 0.1$) is tested.

All the priorities calculated from the pairwise comparison matrices are entered in the appropriate places in the initial supermatrix using Equation (3). A weighted supermatrix is formed and then raised to limiting powers by Equation (4) to capture all the interactions and to obtain a steady-state outcome. Result shows the alternative with the largest priority should have the best overall performance (see TABLE 3.). The performance of the three alternatives are: A_1 (HC_1: 0.281), A_2 (HC_2: 0.324), A_3 (HC_3: 0.394).

TABLE 3. The limit supermatrix

	G	O_1	O_2	O_3	O_4	O_5	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	A1	A2	A3
G	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
O_1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
O_2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
O_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
O_4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
O_5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
C_1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
C_2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
C_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
C_4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
C_5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
C_6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
C_7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
C_8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
C_9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
C_{10}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
C_{11}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
C_{12}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
C_{13}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
A1	**0.281**	0.330	0.380	0.147	0.193	0.462	0.298	0.261	0.593	0.562	0.221	0.182	0.089	0.080	0.142	0.099	0.097	0.304	0.562	**1**	0	0
A2	**0.324**	0.240	0.236	0.506	0.355	0.236	0.163	0.207	0.189	0.188	0.220	0.224	0.621	0.620	0.733	0.549	0.346	0.203	0.223	0	**1**	0
A3	**0.394**	0.430	0.384	0.347	0.453	0.302	0.540	0.532	0.218	0.250	0.559	0.594	0.291	0.300	0.125	0.351	0.557	0.493	0.215	0	0	**1**

RESULTS AND CONCLUSIONS

This research combines the FDM and the ANP, as well as the consensus opinions of experts, to develop an evaluation model for sustainable development of collective residence environment. The results of this research are briefly listed here.

First, through the objective and simple process of FDM, a large number of abstract, qualitative and sensational possible impact indicators/factors are evaluated and extracted into a limited number of representative evaluation criteria. In this research, 26 initial possible impact factors are extracted into five dimensions and 13 factors. The consensus value of G^i from the experts shows the importance of the possible impact factors. For example, the top rankings include Good dwellings & built environment (8.42) ≻ Safety (8.35) ≻ Community network (8.25) ≻ Greenery open space, and Organizational operation , etc. This reveals that the priority of sustainable development of housing community is to construct a fundamental residential environment with safety and high quality, thereafter, to extend to meet satisfaction of community living requirements. Finally, modern technology could be applied in organizational operation for practical management service.

Second, the ANP, which has the core characteristic of effectively dealing with the interdependent relationship among factors, is adopted to further analyze the results from the FDM. With a network structure, the method systematically reflects the interdependence existing in each evaluation components and calculates the importance of components and alternatives through objective mathematical matrix manipulation. The outcome of the evaluation network model displays the interdependence among the five objectives and inner dependence in each criteria cluster. Furthermore, the model can calculate the performances of the three alternatives under the main goal (A_1 (0.281), A_2 (0.324), A_3 (0.394)) simultaneously, then rank these alternatives ($A_3 \succ A_2 \succ A_1$) to compare and choose the best one (A_3).

To sum up, this paper sets up a network evaluation model, which can transform the abstract concept of sustainable development into an applicable approach. Subjective qualitative characteristics and needs in local housing community can be converted into objective numerical weights for reference. In addition, the results can be not only the foundation to implement the sustainable conception, but also the consultation and guidance for planning and practicing in the future.

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