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A Study of the Built Environment Design Elements Embedded into the Multiple Criteria Strategic Planning Model for an Urban Renewal

Wann-Ming Wey

***Abstract*—**The link between urban planning and design principles and the built environment of an urban renewal area is of interest to the field of urban studies. During the past decade, there has also been increasing interest in urban planning and design; this interest is motivated by the possibility that design policies associated with the built environment can be used to control, manage, and shape individual activity and behavior. However, direct assessments and design techniques of the links between how urban planning design policies influence individuals are still rare in the field. Recent research efforts in urban design have focused on the idea that land use and design policies can be used to increase the quality of design projects for an urban renewal area's built environment. The development of appropriate design techniques for the built environment is an essential element of this research. Quality function deployment (QFD) is a powerful tool for improving alternative urban design and quality for urban renewal areas, and for procuring a citizen-driven quality system. In this research, we propose an integrated framework based on QFD and an Analytic Network Process (ANP) approach to determine the Alternative Technical Requirements (ATRs) to be considered in designing an urban renewal planning and design alternative. We also identify the research designs and methodologies that can be used to evaluate the performance of urban built environment projects. An application in an urban renewal built environment planning and design project evaluation is presented to illustrate the proposed framework.

***Keywords*—**Analytic Network Process, Built Environment, Quality Function Deployment, Urban Design, Urban Renewal.

I. Introduction

INNOVATIVE approaches to urban environmental planning and management, such as sustainable development, new urbanism, and smart growth, have been proposed and widely discussed [2] [5]. The important concern of built environment planning and design to urban renewal areas is a critical issue in the urban planning process because of its enormous impact on the economy, ecology, and environmental health of the region. To reach the objective of developing high-quality as well as low-cost outcomes for urban environment planning, selecting an optimal solution from the proposed urban renewal project alternatives via an integrated new model is important. In addition, this kind of selection is also related to the allocation of an organization's limited resources [27].

New approaches to the sustainable environment planning, design, and management of urban regions will depend upon improvements in our knowledge of the causes, chronology, and effects of the urbanization process and their driving forces [12] [15]. Worsening conditions of crowding, housing shortages, insufficient or obsolete infrastructure, increasing urban climatological and ecological problems, and urban security underline a greater-than-ever need for effective management and planning of urban regions [17]. Built environment planning and design for urban renewal means identifying those projects with the greatest cost-benefit to the organization and those that will make allocating resources more efficient. Achieving this objective is difficult because there are many multiple factors, such as planning technical requirements, design needs, and limited availability of urban renewal resources, in candidate urban renewal projects. Built environment planning and design to urban renewal problems are interfunctional planning and communications problems that combine both top-down technical requirements and real user bottom-up needs.

Quality function deployment (QFD) is a technique that aims at customer (user/citizen) satisfaction from the very beginning, namely the alternative design phase. It enables public and private organizations to become proactive about quality problems rather than simply being reactive by responding to user complaints. As an interdisciplinary team process, QFD is used to plan and design new and improved alternatives and services. QFD uses a cross-functional team to determine user needs and translate them into alternative designs through a structured and well-documented framework.

QFD helps organizations maintain their competitiveness by using three strategies: decreasing costs, increasing revenues, and reducing the time to produce new alternatives and services (cycle-time reduction). QFD also allows for organizations to allocate resources and coordinate skills and functions based on user needs, and thus may result in lower alternative costs by ignoring aspects that mean little or nothing to the user. Its systematic nature also permits evaluating the necessary decisions for change and development at the beginning of the design process, which can reduce and even preclude mid-project changes and corrections. Because it enables developing the proper alternative or service with the lowest possible cost, QFD attracts users, which results in higher "selling" rates, which, in turn, leads to greater public benefits. In this way, QFD facilitates the entire development process, minimizing the corrections and waste during this phase, and optimizing the time required for introducing a new or improved alternative or service such as built environment planning and design strategy to urban renewal areas.

QFD was first conceptualized in the late 1960s [1]. After the article by Kogure and Akao (1983), QFD was introduced to the

Wann-Ming Wey is with National Taipei University, Taiwan, R.O.C.(e-mail:wmwey@mail.ntpu.edu.tw)

USA and began to play an important role at many companies [19]. The basic concept of QFD is to translate the desires of users into alternative technical requirements (ATRs) or project engineering characteristics, and subsequently into parts characteristics, process plans, and alternative requirements. To establish these relationships, QFD usually requires four matrices: alternative planning, parts planning, process planning, and alternative planning. The alternative planning matrix translates user needs into alternative design requirements, and the resultant useful concept is then embedded into the urban built environment planning and design process. In this paper, we focus on the first of the four matrices, also called the house of quality (HOQ). There has been some research on quantifying the planning issues in HOQ within the past decade, mainly focusing on user needs. Chan, Kao, Ng, and Wu (1999) and Khoo and Ho (1996) use fuzzy set theory to rate user needs. Other researchers use the analytic hierarchy process (AHP) to determine the degree of importance of user needs [3] [16] [18].In this paper, we propose a novel approach for determining urban renewal ATRs that will be considered in designing the alternative by integrating two decision-making techniques, namely the analytic network process (ANP) and zero-one goal programming (ZOGP). The concept of the integrated approach proposed in this research is borrowed from the framework of QFD and adapted here to the application of built environment planning and design for urban renewal areas. The ANP is a decision aid for incorporating dependence issues into the analysis. Hence, it enables us to take into account the degree of interdependence between urban citizens' needs and ATRs, and the inner dependence between them. Although the ANP facilitates the analysis involving the dependence of ATRs on citizen needs, inner dependence within citizen needs and inner dependence within ATRs, it falls short of taking into account resource limitations and other metrics required in determining the ATRs for alternative design. Wasserman (1993) developed a linear programming model for maximizing citizen satisfaction subject to a budget constraint in QFD planning. Considering the multi-objective nature of the design problem, and having calculated the final relative importance of the ATRs via the ANP, we use the highest possible consideration of these ATRs in the design phase as a goal to be satisfied along with other goals such as cost budget, extendibility, and manufacturability of the ATRs. Extendibility incorporates to what degree improvements in one ATR can be extended to other ATRs, and thus enables an ATR with a high cost but also with high extendibility to be considered as worthwhile in alternative improvement. Manufacturability highlights the difficulties, which are efforts required to implement the desired improvement. For instance, one ATR could require a unique technology for improvement, whereas another ATR could be easily improved with present technology. The relative importance weights of these goals are determined by pairwise comparisons. The ZOGP model is used to determine the ATRs, which will be taken into account in the design phase, in a way that minimizes deviations from the prioritized goals.This paper is organized as follows. Section 2 briefly describes the HOQ with a concise treatment of its steps. Section 3 presents [a] the basics of the ANP and [b] the supermatrix approach developed by Saaty [21] [22]. Section 4, discusses the decision methodology to determine the ATRs to be considered in urban renewal alternative design. Section 5, applies the developed procedure to the design of an urban renewal project. Section 6 provides the concluding remarks.

II. The House Of Quality

In today's competitive environment, the HOQ is a key strategic tool to aid organizations in developing alternatives that satisfy their user needs. The HOQ is a kind of conceptual map that provides the means for interfunctional planning and communications [10] The important seven elements of the HOQ are as follows:

(1) User needs (WHATs). They are also known as the voice of the user, user attributes, user requirements, or demanded quality. As the initial input for the HOQ, they highlight the alternative characteristics that should be paid attention to. User needs, usually collected by focus groups or individual interviews, should be expressed in the users' own phrases. Individual one-to-one interviews may be more cost-effective than focus groups, and at least 20-30 users should be interviewed to obtain 90-95% of all the possible user needs [9]. Mail or telephone surveys should be avoided due to the difficulties in controlling the scope of responses.Preserving the users' own words usually causes problems during the phase of translation and interpretation, because they are usually too general or detailed to be directly used as user needs. To overcome this problem, a number of approaches are used. Initially the words are collected, and then they are organized to form a tree-like hierarchy, usually with three or four levels. Those at the appropriate level are chosen as the final user needs. An affinity diagram, which is a method used to gather large amounts of qualitative data and to organize them into subgroupings based on the similarities between them, can be used for this purpose [7]. Cluster analysis can also be used to form and structure user needs [9].

(2) ATRs (HOWs). ATRs are also known as design requirements, alternative features, engineering attributes, engineering characteristics, or substitute quality characteristics. They can also be developed using the affinity diagram and tree diagram. They describe the alternative in the language of the engineer; therefore, they are sometimes referred to as the voice of the company. The ATRs are used to determine how well the company satisfies the user needs. User needs tell the company "what to do", while the ATRs tell "how to do it". They must be stated in measurable and benchmarkable terms, e.g., for a pencil, lead dust generated in milligrams.

(3) Relative importance of the user needs. Because the collected and organized data from the user usually contain too many needs to deal with simultaneously, they must be rated. The company should trade off one benefit against another, and work on the most important needs while disregarding relatively unimportant ones. In this manner, users are surveyed for each

WHAT using 5-, 7-, or 9-point scales. A more detailed 1-to-10 and anchored scale can also be used. In contrast to determining user needs, the importance of user needs is obtained through mail or telephone surveys. Focus groups and individual interviews are not appropriate because, to ensure statistical significance, a large number of people must be surveyed, which would raise the cost of the survey.

(4) Relationships between WHATs and HOWs. The relationship matrix indicates how much each ATR affects each user need. The relations can be presented in numbers or in symbols. We use numbers.

(5) Inner dependence among user needs. In general, user needs are inner dependent. Some of them will support each other, but others will adversely affect the achievement of others. These supporting and conflicting needs can be identified by a correlation matrix emphasizing necessary trade-offs.

(6) Inner dependence among ATRs. The HOQ's roof matrix is used to specify the various ATRs that must be collaterally improved; this provides a basis for calculating to what extent a change in one feature will affect other features. A desirable change in one feature may have a negative effect on another feature. This correlation facilitates the necessary engineering impacts and trade-offs.

(7) Overall priorities of the ATRs and additional goals. The results obtained from the preceding steps are used to calculate a final rank order of HOWs, also called ATR ratings. Additional design metrics, such as cost, extendibility, and manufacturability, can also be incorporated into the analysis at this step (Shillito, 1994). These metrics help in determining priorities and directions for improvement, as well as providing an objective means of assuring that requirements have been met.A structured communication device, the HOQ, is built using these seven elements. With its design-oriented nature, the HOQ is not only a valuable resource for designers but also a way to summarize and convert feedback from users into information for engineers. In addition, marketing can benefit from it since it is based on the voice of the user, and upper management can use it to develop strategic opportunities. Hence, the HOQ strengthens vertical and horizontal communications. Once having identified critical ATRs that demand change, they will be driven to the next matrix as WHATs to identify the critical parts characteristics. Similarly, the manufacturing operations and the day-to-day operations and controls are defined. Thus, finally, the company has in its hands an alternative that fulfills both user needs and producer requirements within a shorter development time.

The HOQ of an urban renewal built environment planning and design can be represented as in Fig. 1.

III. The Analytic Network Process

The AHP is a well-known technique that decomposes a problem into several levels in such a way that they form a hierarchy [20]. Each element in the hierarchy is supposed to be independent, and a relative ratio scale of measurement is derived from pairwise comparisons of the elements in a level of the hierarchy with respect to an element of the preceding level. However, in many cases, criteria and alternatives are interdependent.

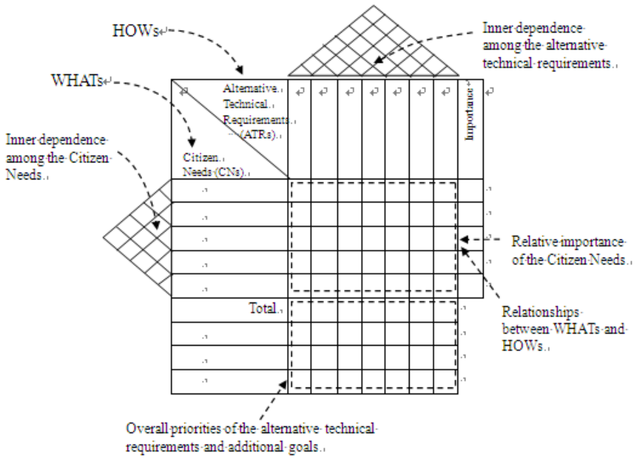
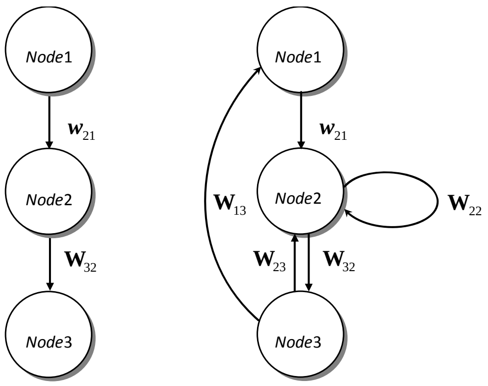


Fig. 1 The HOQ of an urban renewal built environment planning and design

The ANP can be used as an effective tool in those cases where the interactions among the elements of a system form a network structure [21].While the AHP uses a unidirectional hierarchical relationship among decision levels, the ANP enables interrelationships among the decision levels and allows attributes to be taken into consideration in a more general form. The ANP uses ratio scale measurements based on pairwise comparisons; however, it does not impose a strict hierarchical structure as in the AHP, and it models a decision problem using a systems-with-feedback approach. Figure 2a and b shows the structural difference between the hierarchy and network. Nodes of the network represent components of the system, and arcs denote interactions between them. The directions of the arcs represent dependence, whereas loops signify the inner dependence of the elements in a cluster: a hierarchy is a simple and special case of a network.The ANP generalizes the AHP by replacing hierarchies with networks [21](Saaty, 1996, 2005) and allowing more complex interrelationships (e.g., interdependence and feedback) in a network system. It enhances the function of the AHP to develop a complete model that can incorporate interdependent relationships among elements from different levels or within levels, which are assumed to be uncorrelated in the AHP (Cheng & Li, 2007). The ANP has been widely used in multiple attribute decision analysis (MADA) problems in various fields such as environmental management, multi-dimensional forecasting, strategic decision, project selection, alternative planning, and so on (Chung, Lee, & Pearn, 2005; Wu & Lee, 2007).Fig. 2 depicts the difference in structures and the corresponding supermatrix between a hierarchy and a network. A node represents a component (or cluster) with elements inside it; a straight line or an arc denotes the interactions between two components; and a loop indicates the inner dependence of elements within a component (Sarkis, 2002). When the elements of a component *Node*1 depend on another component *Node*2, this relation is represented with an arrow from component *Node*1 to *Node*2. The corresponding supermatrix of the hierarchy with three levels of clusters is also shown: where $\boldsymbol{w}_{21}$ is a vector that represents the impact of the *Node*1 on the *Node*2; $\mathbf{W}_{32}$ is a matrix that represents the impact of the *Node*2 on each element of the *Node*3; and **I** is the identity matrix. A hierarchy is a simple and special case of a network.



$$\mathbf{W}_h = \begin{array}{c} \\ Node1 \\ Node2 \\ Node3 \end{array} \begin{array}{c} \begin{array}{ccc} Node1 & Node2 & Node3 \end{array} \\ \begin{bmatrix} 0 & 0 & 0 \\ \boldsymbol{w}_{21} & 0 & 0 \\ 0 & \mathbf{W}_{32} & \mathbf{I} \end{bmatrix} \end{array} \qquad \mathbf{W}_n = \begin{array}{c} \\ Node1 \\ Node2 \\ Node3 \end{array} \begin{array}{c} \begin{array}{ccc} Node1 & Node2 & Node3 \end{array} \\ \begin{bmatrix} 0 & 0 & \mathbf{W}_{13} \\ \boldsymbol{w}_{21} & \mathbf{W}_{22} & \mathbf{W}_{23} \\ 0 & \mathbf{W}_{32} & \mathbf{I} \end{bmatrix} \end{array}$$

Fig. 2 (a) Linear hierarchy and (b) Nonlinear network

The ANP is a general theory of relative measurement used to derive composite-priority-ratio scales from individual-ratio scales that represent the relative influence of factors that interact with respect to control criteria (Niemira & Saaty, 2004). Through the "supermatrix", which is composed of matrices of column priorities, the ANP framework catches the consequence of dependence and feedback within and among components. A standard supermatrix form is as follows (Saaty & Vargas, 1998):

$$W = \begin{array}{cc} & \\ C_1 & \begin{array}{c} e_{11} \\ \vdots \\ e_{1n_1} \end{array} \\ \vdots & \vdots \\ C_k & \begin{array}{c} e_{k1} \\ \vdots \\ e_{kn_k} \end{array} \\ \vdots & \vdots \\ C_N & \begin{array}{c} e_{N1} \\ \vdots \\ e_{Nn_N} \end{array} \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & \cdots & C_k & \cdots & C_N \\ e_{11}\cdots e_{1n_1} & \cdots & e_{k1}\cdots e_{kn_k} & \cdots & e_{N1}\cdots e_{Nn_N} \end{array} \\ \begin{bmatrix} W_{11} & \cdots & W_{1k} & \cdots & W_{1N} \\ \vdots & & \vdots & \ddots & \vdots \\ W_{k1} & \cdots & W_{kk} & \cdots & W_{kN} \\ \vdots & & \vdots & \ddots & \vdots \\ W_{N1} & \cdots & W_{Nk} & \cdots & W_{NN} \end{bmatrix} \end{array} \qquad (1)$$

Let the components of a network system be C_k, k = 1,..., N, and let each component k have nk 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. **W**ij shows the influence of the elements in the ith component to the elements in the jth component, and vice versa. In addition, if there is no influence, then **W**ij = 0 (Huang, Tzeng, & Ong, 2005; Yu & Tzeng, 2006)

The process of the ANP is described as follows (Meade & Sarkis, 1998; Saaty, 1996):

Step 1: Model Construction and Problem Structuring

The problem should be stated clearly by decision makers and be decomposed into a rational system like a network, which represents the relationship of feedback or interdependence among the components. An example (Momoh & Zhu, 1998) is shown in Fig. 3.

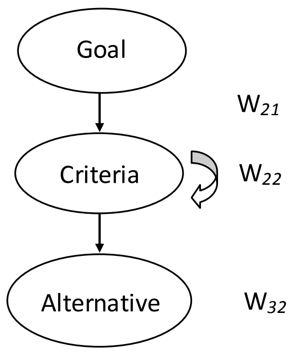


Fig. 3 Network example

*Step 2: Pairwise Comparisons Matrices and Priority Vector*s

Like AHP, decision elements at each component are compared pairwisely with respect to their importance toward s their control criterion, and the components themselves are also compared pairwisely with respect to their contribution to the goal (Chung et al., 2005b). The relative importance values are determined using a scale of 1 to 9, and an eigenvector can be obtained. A consistency index (CI) and consistency ratio (CR) are calculated next [21]. If an inconsistent judgment is found, that part of the pairwise comparison must be performed again. For the example in Fig. 3, the criteria are interrelated among themselves and W22 indicates the interdependency; W21 is a matrix that represents the impact of the goal on the criteria, and W32 is a matrix that represents the impact of criteria on each of the alternatives (Momoh & Zhu, 1998).

Step 3: Supermatrix Formation

To generate 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:

$$W = \begin{array}{c} \\ Goal \\ Criteria \\ Alternatives \end{array} \begin{array}{c} \begin{array}{ccc} Goal & Criteria & Alternatives \end{array} \\ \begin{bmatrix} 0 & 0 & 0 \\ W_{21} & W_{22} & 0 \\ 0 & W_{32} & I \end{bmatrix} \end{array} \qquad (2)$$

where "I" is the identity matrix, and the zeros correspond to those elements that have no influence. After forming the supermatrix, a weighted supermatrix is derived by transforming the sum of each column to unity, i.e., like the concept of a Markov chain for ensuring a column-stochastic matrix (Huang et al., 2005). Next, to achieve a convergence on the importance weights, the weighted supermatrix is raised to limiting powers by Refer to (3) to obtain the limit supermatrix [21] Yu & Tzeng, 2006), which shows the long-term stable weighted values (Chung et al., 2005) and the global priority weights. Details of mathematical processes of the ANP approach can can be found in Saaty (1996).

$$\lim_{k\to\infty} W^{2k+1} \tag{3}$$

Step 4: Selection of Best Aalternatives.

If the supermatrix formed in *Step 3* covers the whole network; the priority weights of alternatives can be found in the column of alternatives-to-goal in the limit supermatrix (Sarkis, 2003).The process for solving the prioritization of interdependent disaster resilience indicators is summarized as follows: To consider interdependence, the first step is to identify the multiple indicators that merit consideration and then draw a relationship that shows the degree of interdependence among the indicators. Next is to determine the degree of influence between the indicators. When comparing the indicators for each indicator, the decision maker will respond to questions such as: “In comparing indicators A and B, on the basis of cost reduction, which indicator is preferred?” The responses are presented numerically, scaled on the basis of Saaty's proposed 1-9 scale [20] [21] with reciprocals, in a project comparison matrix. The final step is to determine the overall prioritization of these disaster resilience indicators.When a network consists of only two clusters apart from the goal, namely criteria and alternatives, the matrix manipulation approach proposed by Saaty and Takizawa (1986) can be used to deal with the dependence of the elements of a system. We use this approach, which will be described in Section 5, to incorporate the dependencies inherent in the QFD process into the analysis.

IV. The Decision Methodology

The decision algorithm addresses the problem of selecting the ATRs on which to focus in the design process considering the predetermined goals. The algorithm can be divided into two major phases. In the first phase, we construct the HOQ using the ANP approach, and in the second phase, we integrate the ANP results with a ZOGP model to determine the set of ATRs that the design team needs to concentrate on. The ANP approach, which allows for modeling interrelationships within the HOQ, is used to determine the representation of the voice of the citizen in the HOQ, considered as one of the goals within the decision framework. There are other goals such as cost budget, extendibility, and manufacturability that need to be taken into account in the analysis. The unit budget costs with respect to ATRs are determined, and the priorities of the ATRs with respect to goals such as extendibility and manufacturability are obtained using pairwise comparisons. After that, the adjusted priorities of the ATRs with respect to these goals are calculated to account for dependencies encountered in the HOQ. The relative importance weights of the goals that are taken into consideration then are computed using pairwise comparisons. Finally, all the previously calculated data are integrated within a ZOGP formulation to determine the ATRs to be considered in the design process.We prefer using weighted ZOGP as a decision tool since it can handle multiple objectives and seeks to minimize the total deviation from the desired goals. This property of ZOGP enables us to incorporate multiple goals, including cost budget, extendibility, and manufacturability, into the alternative design process. The weighted goal programming model considers all the goals simultaneously by forming an achievement function that minimizes the total weighted deviation from all the goals stated in the model. The weights are not preemptive but reflect the decision makers’ preferences regarding the relative importance of each goal. The incommensurability issue faced in weighted goal programming when using goals that are measured in different units, such as the cost budget goal and the extendibility goal, can be resolved using a normalization scheme [24].In formulating goal programming models that include multiple qualitative goals, a method based on pairwise comparisons, such as AHP or ANP, appears to be an effective means for assessing relative weights. There are numerous published studies in diverse areas that use integrated AHP and ZOGP models and conclude that combined models provide more realistic solutions by avoiding infeasibility (Badri, 1999 [25]. The ANP enables the modeling of more complex relationships, which includes dependence among decision levels, and thus will be used in the integrated decision approach proposed in this paper.The first step of the algorithm is identifying the citizen needs and ATRs. The second is determining the importance of the citizen needs, which corresponds to the first step of the matrix manipulation concept of the ANP [14] [22]. The third is filling in the body of the HOQ with the weights obtained by comparing the ATRs with respect to each citizen need, and, finally, the fourth is obtaining the interdependent priorities of the ATRs by analyzing dependence among the citizen needs and ATRs, respectively.The supermatrix representation of the QFD model used in this paper is as follows:

$$W' = \begin{array}{l} \\ Goal(G) \\ CN_s \\ ATR_s \end{array} \begin{array}{c} \begin{array}{ccc} G & CN_s & ATR_s \end{array} \\ \begin{bmatrix} 0 & 0 & 0 \\ w_1 & W_3 & 0 \\ 0 & W_2 & W_4 \end{bmatrix} \end{array} \tag{4}$$

Where CN_S (= Citizen Needs) stands for the citizen needs in the urban renewal built environment with respect to the demand side for QFD. However, ATR_S (= Alternative Technical Requirements) stands for the technical requirements of urban renewal alternatives with respect to the planning and design

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side for QFD.For an urban renewal built environment planning and design project, the decision methodology for the QFD can be presented in terms of the ANP supermatrix representation containing the CNs and the ATRs shown as Fig 4.

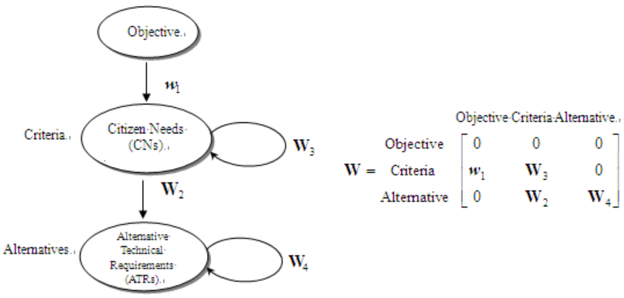

Fig. 4 ANP supermatrix representation of QFD methodology

The stepwise representation of the algorithm to determine the set of ATRs to be considered in designing an urban renewal alternative is then as follows:

Step 1. Identify the CNs and the ATRs.

Step 2. Considering the interdependencies within the HOQ, determine the overall priorities of the ATRs using the ANP approach.

Step 3. Identify the unit measures and limits of the first-type metrics related to resource limitations.

Step 4. Determine the preference ratings of the ATRs with respect to additional design goals (named here as second-type metrics) using pairwise comparison.

Step 5. Compute the adjusted unit measures concerning the resource limitations and the adjusted priorities of the ATRs with respect to additional design goals to account for dependencies encountered in the HOQ.

Step 6. Calculate the relative importance weights of the determined goals using pairwise comparisons.

Step 7. Formulate and solve the ZOGP model to determine the set of ATRs to be considered in the design process.

To determine the set of ATRs that will be considered in alternative design, we construct a ZOGP model using the first-phase results and goals related to other metrics of the ATRs such as cost, extendibility, and manufacturability. The set of metrics contains two types of specifications: metrics that have some sort of resource limitations, e.g., cost, and the second-type metrics that result in a rate of preference for ATRs such as extendibility and manufacturability. To incorporate the second-type metrics into the formulation, we determine a preference rating for each ATR using pairwise comparisons, and we penalize the negative deviation of these metrics from 1 in the objective function. Following El-Gayar and Leung (2001) to rectify the likely incommensurability problem related to individual goals, the general form of the ZOGP model employed in the decision framework is as follows:

$$Min\ \omega_1^{ANP}\left(d_1^-\right)+\sum_{i=2}^{s}\omega_i\left(\frac{d_i^-}{R_i}+\frac{d_i^+}{R_i}\right)+\sum_{i=s+1}^{m}\omega_i\left(d_i^-\right)$$

s.t.

$$\sum_{j=1}^{n} w_j^{ANP}x_j+d_1^- - d_1^+ = 1$$

$$\sum_{j=1}^{n} r_{ij}x_j+d_i^- - d_i^+ = R_i\,,\ i=2,\dots,s \tag{5}$$

$$\sum_{j=1}^{n} w_{ij}x_j+d_i^- - d_i^+ = 1\,,\ i=s+1,\dots,m$$

$$x_j\in\{0,1\},\ j=1,\dots,n \qquad d_i^-,d_i^+\geq 0,\ i=1,\dots,m$$

where the ω_i are the weights of the goals $(i=1,2,\dots,m)$, d_i^- and d_i^+ represent the negative and positive deviation variables of the ith goal (i = 1,…,m), x_j is the binary selection variable representing the jth ATRs (j = 1, …,n), w_j^{ANP} denotes the interdependent priority of the jth ATR (j = 1,…,n), r_{ij} indicates the amount of the ith resource used by the jth ATR (i = 2,…,s; j = 1,…,n), R_i represents the limitation of the ith resource, and w_{ij} is the preference rating of the jth ATR with respect to the metric i (i = s + 1,…,m; j = 1,…,n).

V. An Empirical Example Of Urban Renewal Built Environment Project In Taipei City

This section presents an illustration of the developed decision procedure based on an empirical example of an urban renewal built environment in Taipei City, Taiwan. The urban renewal project was in the Wanhua District of Taipei City (Fig. 5).

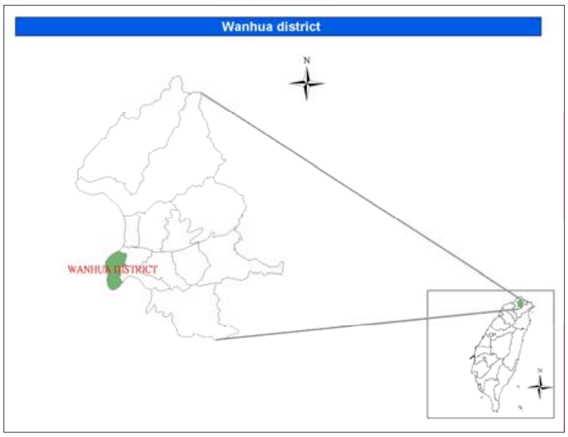

Fig. 5 Wanhua District urban renewal project

The algorithm presented in Section 4 is applied to determine the ATRs to be considered in developing an urban renewal design. Figure 6 shows the HOQ for the design of an urban renewal built environment. The application is shown in stepwise form as given below. Due to space limitations, only a limited number of pairwise comparison matrices are presented, and the resulting weight vectors are generally provided without the corresponding pairwise comparison matrices in the illustration.

Step 1. As mentioned in Section 2, the QFD alternative planning process begins by determining the CNs and then the ATRs. The collected and organized citizen phrases are placed in the upper left part of the HOQ. In our example, the nine CNs for designing an urban renewal alternative—determined as the most important according to a survey—are listed in Table I. Having agreed upon the CNs, the ATRs that are likely to affect those needs are also identified (Table Ⅱ).

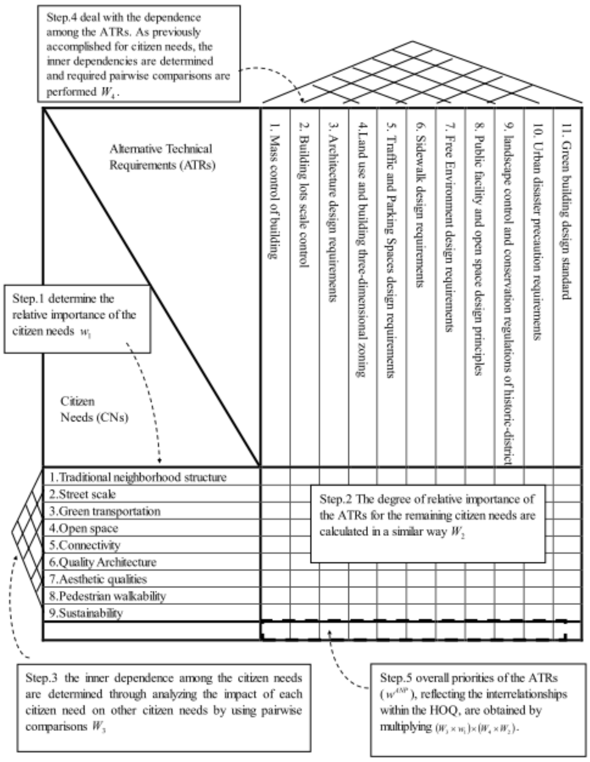

Fig. 6 HOQ for the design of an urban renewal built environment

TABLE I
URBAN DESIGN CRITERIA OF CNs

Citizen Needs Dimension	Criteria
Physical dimension of urban design	1.Traditional neighborhood structure (Principles of Urbanism, 2009)
	2.Street scale (Handy, 2002)
	3.Green transportation (Principles of Urbanism, 2009)
	4.Open space (Duany Plater-Zyberk & Company, 2001)
	5.Connectivity (Yan Song, 2003; Benfield et al., 1999)
	6.Quality Architecture (Principles of Urbanism, 2009)
Non- Physical (Psychological) dimension of urban design	7.Aesthetic qualities (Handy, 2002)
	8.Pedestrian walkability (Yan Song, 2003; Frank & Englke, 2003)
	9.Sustainability (Principles of Urbanism, 2009)

TABLE Ⅱ
URBAN DESIGN ALTERNATIVE TECHNICAL REQUIREMENTS

URBAN DESIGN DIMENSION	URBAN DESIGN REGULATION
LAND AND ARCHITECTURE USE PLANNING	1. MASS CONTROL OF BUILDING
	2. BUILDING LOTS SCALE CONTROL
	3. ARCHITECTURE DESIGN REQUIREMENTS
	4. LAND USE AND BUILDING THREE-DIMENSIONAL ZONING
TRAFFIC AND PARKING SPACES PLANNING IN CONSTRUCTION SITE	5. TRAFFIC AND PARKING SPACES DESIGN REQUIREMENTS
	6. SIDEWALK DESIGN REQUIREMENTS
	7. FREE ENVIRONMENT DESIGN REQUIREMENTS
OPEN SPACE AND PLANTING DESIGN STANDARD	8. PUBLIC FACILITY AND OPEN SPACE DESIGN
URBAN RENEWAL UNIT PLANNING AND DESIGN ZONING BONUS STANDARD	9. LANDSCAPE CONTROL AND CONSERVATION REGULATIONS OF HISTORIC-DISTRICT
	10.URBAN DISASTER PRECAUTION REQUIREMENTS
	11.GREEN BUILDING DESIGN STANDARD

Step 2. In this step, we initially determine the relative importance of the CNs by asking the following question: “Which CNs should be emphasized more in designing an urban renewal alternative, and how much more?” Assuming that there is no dependence among the CNs, the following eigenvector for the CNs is obtained by performing pairwise comparisons with respect to the goal of achieving the best design

$$w_1 = \begin{bmatrix} \text{1. Traditiona l neighborho od structure} \\ \text{2. Street scale} \\ \text{3.Green tr ansportati on} \\ \text{4.Open space} \\ \text{5.Connecti vity} \\ \text{6.Quality Architectu re} \\ \text{7.Aestheti c qualities} \\ \text{8.Pedestri an walkabi lity} \\ \text{9.Sustaina bility} \end{bmatrix} = \begin{bmatrix} 0.3265 \\ 0.0506 \\ 0.0337 \\ 0.2196 \\ 0.1315 \\ 0.0721 \\ 0.1232 \\ 0.0214 \\ 0.0214 \end{bmatrix}$$

Then, assuming that there is no dependence among the ATRs, they are compared with respect to each citizen need yielding the column eigenvectors regarding each citizen need. The degrees of relative importance of the ATRs for the remaining CNs are calculated in a similar way and presented in Table Ⅲ. The transpose of the data shown in Table Ⅲ will be placed in the body of the HOQ.

TABLE III
THE COLUMN EIGENVECTORS WITH RESPECT TO EACH CITIZEN NEED

W2	ATR_1	ATR_2	ATR_3	ATR_4	ATR_5	ATR_6	ATR_7	ATR_8	ATR_9	ATR_{10}	ATR_{11}
C1	0.125	0.094	0.094	0.078	0.063	0.109	0.063	0.125	0.125	0.094	0.031
C2	0.143	0.171	0.114	0.143	0.000	0.029	0.143	0.086	0.000	0.171	0.000
C3	0.135	0.054	0.162	0.081	0.000	0.162	0.162	0.000	0.000	0.000	0.243
C4	0.109	0.127	0.018	0.109	0.000	0.127	0.109	0.164	0.055	0.145	0.036
C5	0.056	0.111	0.167	0.000	0.000	0.167	0.194	0.167	0.028	0.083	0.028
C6	0.143	0.054	0.161	0.107	0.000	0.089	0.107	0.071	0.036	0.107	0.125
C7	0.146	0.125	0.167	0.104	0.021	0.146	0.063	0.125	0.021	0.021	0.063
C8	0.031	0.094	0.031	0.125	0.219	0.188	0.156	0.063	0.031	0.000	0.063
C9	0.102	0.119	0.085	0.068	0.017	0.102	0.085	0.068	0.102	0.119	0.136

$W_2 =$

	CN_1	CN_2	CN_3	CN_4	CN_5	CN_6	CN_7	CN_8	CN_9
ATR_1	0.1250	0.1429	0.1351	0.1091	0.0556	0.1429	0.1458	0.0312	0.1017
ATR_2	0.0938	0.1714	0.0540	0.1273	0.1111	0.0536	0.1250	0.0938	0.1187
ATR_3	0.0938	0.1143	0.1622	0.0181	0.1667	0.1608	0.1668	0.0312	0.0847
ATR_4	0.0781	0.1429	0.0811	0.1091	0.0000	0.1071	0.1042	0.1250	0.0678
ATR_5	0.0625	0.0000	0.0000	0.0000	0.0000	0.0000	0.0208	0.2188	0.0169
ATR_6	0.1094	0.0285	0.1622	0.1273	0.1667	0.0893	0.1458	0.1875	0.1017.
ATR_7	0.0625	0.1429	0.1622	0.1091	0.1943	0.1071	0.0625	0.1563	0.0847
ATR_8	0.1250	0.0857	0.0000	0.1636	0.1667	0.0714	0.1250	0.0625	0.0678
ATR9	0.1250	0.0000	0.0000	0.0545	0.0278	0.0357	0.0208	0.0312	0.1017
$ATR1_0$	0.0938	0.1714	0.0000	0.1455	0.0833	0.1071	0.0208	0.0000	0.1187
ATR_{11}	0.0311	0.0000	0.2432	0.0364	0.0278	0.1250	0.0625	0.0625	0.1356

TABLE IV
THE INNER DEPENDENCE MATRIX OF THE CNs

$W_3 =$

	CN_1	CN_2	CN_3	CN_4	CN_5	CN_6	CN_7	CN_8	CN_9
CN_1	0.5077	0.0702	0.0423	0.0000	0.0000	0.0000	0.0000	0.1396	0.1131
CN_2	0.0724	0.5591	0.0809	0.0000	0.0000	0.0000	0.0000	0.2431	0.0734
CN_3	0.0000	0.0000	0.3670	0.0000	0.3333	0.0000	0.0000	0.0000	0.1562
CN_4	0.2120	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0682	0.0292
CN_5	0.1666	0.0000	0.1560	0.0000	0.6667	0.0000	0.0000	0.0629	0.0214
CN_6	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.3333	0.0000	0.1634
CN_7	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.6667	0.0000	0.0984
CN_8	0.0413	0.3707	0.3538	0.0000	0.0000	0.0000	0.0000	0.4862	0.0145
CN_9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3304

TABLE V
THE INNER DEPENDENCE MATRIX OF THE ATRs

$W_4 =$

	ATR_1	ATR_2	ATR_3	ATR_4	ATR_5	ATR_6	ATR_7	ATR_8	ATR_9	ATR_{10}	ATR_{11}
ATR_1	0.6483	0.0000	0.0000	0.0000	0.2500	0.0890	0.0000	0.1095	0.0000	0.1000	0.0000
ATR_2	0.1220	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ATR_3	0.0000	0.0000	0.6483	0.0000	0.0000	0.0000	0.0000	0.0000	0.2500	0.0000	0.0000
ATR_4	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2500
ATR_5	0.0000	0.0000	0.0000	0.0000	0.7500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ATR_6	0.0000	0.0000	0.0000	0.0000	0.0000	0.5876	0.0000	0.0000	0.0000	0.0000	0.0000
ATR_7	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
ATR_8	0.0000	0.0000	0.0000	0.0000	0.0000	0.3234	0.0000	0.5815	0.0000	0.3000	0.0000
ATR_9	0.2297	0.0000	0.2297	0.0000	0.0000	0.0000	0.0000	0.0000	0.7500	0.0000	0.0000
ATR_{10}	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3090	0.0000	0.6000	0.0000
ATR_{11}	0.0000	0.0000	0.1220	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7500

The schematic representation of the relationship between the CNs is shown in Fig. 7. The resulting eigenvectors obtained from pairwise comparisons are presented in Table IV, where zeros are assigned to the eigenvector weights of the CNs that are independent.

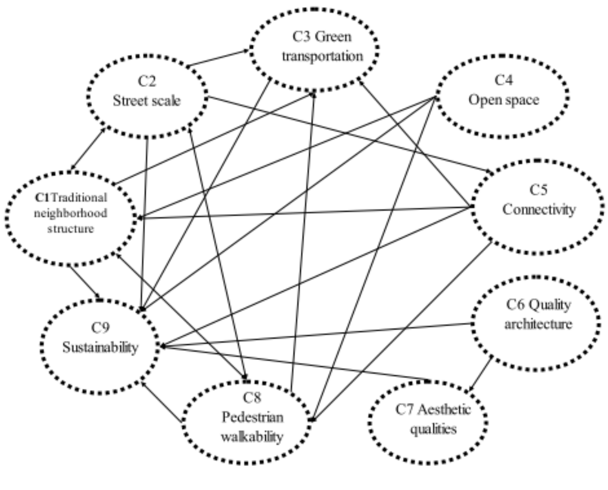

Fig. 7 Inner Dependence among the CNs

Next, we deal with the dependence among the ATRs. As previously accomplished for CNs, the inner dependencies are determined, and required pairwise comparisons are made. The dependencies among the ATRs are depicted in Fig. 8, and the relative importance weights obtained from the pairwise comparisons are presented in Table V

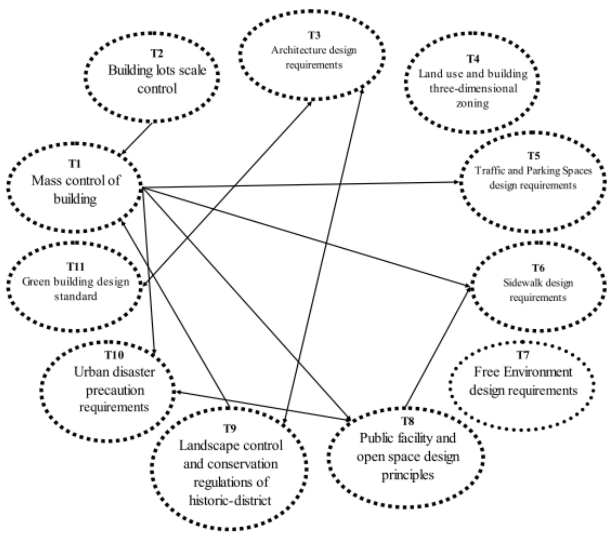

Fig. 8 Inner Dependence among the urban design ATRs

Afterward, we obtain the interdependent priorities of the

CNs ($\boldsymbol{w}_C$) as

$$w_C = W_3 \times w_1 = \begin{bmatrix} 0.5077 & 0.0702 & 0.0423 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.1396 & 0.1131 \\ 0.0724 & 0.5591 & 0.0809 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.2431 & 0.0734 \\ 0.0000 & 0.0000 & 0.3670 & 0.0000 & 0.3333 & 0.0000 & 0.0000 & 0.0000 & 0.1562 \\ 0.2120 & 0.0000 & 0.0000 & 1.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0682 & 0.0292 \\ 0.1666 & 0.0000 & 0.1560 & 0.0000 & 0.6667 & 0.0000 & 0.0000 & 0.0629 & 0.0214 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 1.0000 & 0.3333 & 0.0000 & 0.1634 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.6667 & 0.0000 & 0.0984 \\ 0.0413 & 0.3707 & 0.3538 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.4862 & 0.0146 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.3304 \end{bmatrix} \times$$

$$\begin{bmatrix} 0.3265 \\ 0.0506 \\ 0.0337 \\ 0.2196 \\ 0.1315 \\ 0.0721 \\ 0.1232 \\ 0.0214 \\ 0.0214 \end{bmatrix} = \begin{bmatrix} 0.1761 \\ 0.1053 \\ 0.0157 \\ 0.2909 \\ 0.1491 \\ 0.1167 \\ 0.0842 \\ 0.0549 \\ 0.0071 \end{bmatrix} \begin{matrix} \text{C1 Traditional neighborhood structure} \\ \text{C2 Street scale} \\ \text{C3 Green transportation} \\ \text{C4 Open space} \\ \text{C5 Connectivity} \\ \text{C6 Quality Architecture} \\ \text{C7 Aesthetic qualities} \\ \text{C8 Pedestrian walkability} \\ \text{C9 Sustainability} \end{matrix}$$

Then, the interdependent priorities of the ATRs, $\mathbf{W}_A$, are calculated as follows:

$$W_A = W_4 \times W_2 =$$

$$\begin{bmatrix} 0.6483 & 0.0000 & 0.0000 & 0.0000 & 0.2500 & 0.0890 & 0.0000 & 0.1095 & 0.0000 & 0.1000 & 0.0000 \\ 0.1220 & 1.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.6483 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.2500 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 1.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.2500 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.7500 & 0.0000 & 0..0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.5876 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 1.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.3234 & 0.0000 & 0.5816 & 0.0000 & 0.3000 & 0.0000 \\ 0.0000 & 0.0000 & 0.2297 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.7500 & 0.0000 & 0.0000 \\ 0.2297 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.3090 & 0.0000 & 0.6000 & 0.0000 \\ 0.0000 & 0.0000 & 0.1220 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.7500 \end{bmatrix}$$

$$\times$$

$$\begin{bmatrix} 0.1250 & 0.1429 & 0.1351 & 0.1091 & 0.0556 & 0.1429 & 0.1458 & 0.0313 & 0.1017 \\ 0.0938 & 0.1714 & 0.0541 & 0.1273 & 0.1111 & 0.0536 & 0.1250 & 0.0938 & 0.1186 \\ 0.0938 & 0.1143 & 0.1622 & 0.0182 & 0.1667 & 0.1607 & 0.1667 & 0.0313 & 0.0847 \\ 0.0781 & 0.1429 & 0.0811 & 0.1091 & 0.0000 & 0.1071 & 0.1042 & 0.1250 & 0.0678 \\ 0.0625 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0208 & 0.2188 & 0.0169 \\ 0.1094 & 0.0286 & 0.1622 & 0.1273 & 0.1667 & 0.0893 & 0.1458 & 0.1875 & 0.1017 \\ 0.0625 & 0.1429 & 0.1622 & 0.1091 & 0.1944 & 0.1071 & 0.0625 & 0.1563 & 0.0847 \\ 0.1250 & 0.0857 & 0.0000 & 0.1636 & 0.1667 & 0.0714 & 0.1250 & 0.0625 & 0.0678 \\ 0.1250 & 0.0000 & 0.0000 & 0.0545 & 0.0278 & 0.0357 & 0.0208 & 0.0313 & 0.1017 \\ 0.0938 & 0.1714 & 0.0000 & 0.1455 & 0.0833 & 0.1071 & 0.0208 & 0.0000 & 0.1186 \\ 0.0313 & 0.0000 & 0.2432 & 0.0364 & 0.0278 & 0.1250 & 0.0625 & 0.0625 & 0.1356 \end{bmatrix}$$

$$= \begin{bmatrix} 0.1295 & 0.1217 & 0.1020 & 0.1145 & 0.0774 & 0.1191 & 0.1285 & 0.0985 & 0.0985 \\ 0.1090 & 0.1889 & 0.0705 & 0.1406 & 0.1179 & 0.0710 & 0.1428 & 0.0976 & 0.1311 \\ 0.0998 & 0.0741 & 0.1659 & 0.0345 & 0.1219 & 0.1444 & 0.1289 & 0.0437 & 0.1143 \\ 0.0781 & 0.1429 & 0.0811 & 0.1091 & 0.0000 & 0.1071 & 0.1042 & 0.1250 & 0.0678 \\ 0.0469 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0156 & 0.1641 & 0.0127 \\ 0.0643 & 0.0168 & 0.0953 & 0.0748 & 0.0979 & 0.0525 & 0.0857 & 0.1102 & 0.0598 \\ 0.0625 & 0.1429 & 0.1622 & 0.1091 & 0.1944 & 0.1071 & 0.0625 & 0.1563 & 0.0847 \\ 0.1362 & 0.1105 & 0.0524 & 0.1800 & 0.1758 & 0.1026 & 0.1261 & 0.0970 & 0.1079 \\ 0.1440 & 0.0591 & 0.0683 & 0.0701 & 0.0719 & 0.0965 & 0.0874 & 0.0378 & 0.1191 \\ 0.0949 & 0.1293 & 0.0000 & 0.1378 & 0.1015 & 0.0864 & 0.0511 & 0.0193 & 0.0921 \\ 0.0349 & 0.0139 & 0.2022 & 0.0295 & 0.0412 & 0.1134 & 0.0672 & 0.0507 & 0.1120 \end{bmatrix}$$

After that, overall priorities of the ATRs (wANP), reflecting the interrelationships within the HOQ, are obtained by multiplying $\boldsymbol{W}_A$ and $\boldsymbol{w}_C$.

$$w^{ANP} = W_A \times w_C =$$

$$\begin{bmatrix} 0.1295 & 0.1217 & 0.1020 & 0.1145 & 0.0774 & 0.1191 & 0.1285 & 0.0985 & 0.0985 \\ 0.1090 & 0.1889 & 0.0705 & 0.1406 & 0.1179 & 0.0710 & 0.1428 & 0.0976 & 0.1311 \\ 0.0998 & 0.0741 & 0.1659 & 0.0345 & 0.1219 & 0.1444 & 0.1289 & 0.0437 & 0.1143 \\ 0.0781 & 0.1429 & 0.0811 & 0.1091 & 0.0000 & 0.1071 & 0.1042 & 0.1250 & 0.0678 \\ 0.0469 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0156 & 0.1641 & 0.0127 \\ 0.0643 & 0.0168 & 0.0953 & 0.0748 & 0.0979 & 0.0525 & 0.0857 & 0.1102 & 0.0598 \\ 0.0625 & 0.1429 & 0.1622 & 0.1091 & 0.1944 & 0.1071 & 0.0625 & 0.1563 & 0.0847 \\ 0.1362 & 0.1105 & 0.0524 & 0.1800 & 0.1758 & 0.1026 & 0.1261 & 0.0970 & 0.1079 \\ 0.1440 & 0.0591 & 0.0683 & 0.0701 & 0.0719 & 0.0965 & 0.0874 & 0.0378 & 0.1191 \\ 0.0949 & 0.1293 & 0.0000 & 0.1378 & 0.1015 & 0.0864 & 0.0511 & 0.0193 & 0.0921 \\ 0.0349 & 0.0139 & 0.2022 & 0.0295 & 0.0412 & 0.1134 & 0.0672 & 0.0507 & 0.1120 \end{bmatrix} \times$$

$$\begin{bmatrix} 0.1716 \\ 0.1053 \\ 0.0157 \\ 0.2909 \\ 0.1491 \\ 0.1167 \\ 0.0842 \\ 0.0549 \\ 0.0071 \end{bmatrix} = \begin{bmatrix} 0.1129 \\ 0.1253 \\ 0.0871 \\ 0.0904 \\ 0.0187 \\ 0.0708 \\ 0.1163 \\ 0.1437 \\ 0.0853 \\ 0.1017 \\ 0.0478 \end{bmatrix} \begin{matrix} \text{ATR}_1 \text{ Mass control of building} \\ \text{ATR}_2 \text{ Building lots scale control} \\ \text{ATR}_3 \text{ Architecture design requirements} \\ \text{ATR}_4 \text{ Land use and building three-dimensional zoning} \\ \text{ATR}_5 \text{ Traffic and Parking Spaces design requirements} \\ \text{ATR}_6 \text{ Sidewalk design requirements} \\ \text{ATR}_7 \text{ Free Environment design requirements} \\ \text{ATR}_8 \text{ Public facility and open space design principles} \\ \text{ATR}_9 \text{ landscape control and conservation regulations of historic-district} \\ \text{ATR}_{10} \text{ Urban disaster precaution requirements} \\ \text{ATR}_{11} \text{ Green building design standard} \end{matrix}$$

Step 3. We construct the ZOGP model using the previous steps of refer to (5) and the data obtained from Taipei City, Taiwan

It is worth pointing out that the coefficients of the mathematical GP model can be represented with priorities obtained with relative (i.e., pairwise comparisons) measurement as shown in the previous section. The result is that when measurement scales exist, the solution to the relative goal programming model (with coefficients of objective function in the ZOGP model normalized to unity to make them correspond to priorities obtained with relative measurement) and the solution to the ZOGP model (the "usual" model with measurements and physical scales) are the same to within a multiplicative constant (Saaty et al., 2003). It is then possible to construct ZOGP models using solely relative measurement to optimize the allocation of resources. Thus, the objective function of our proposed ZOGP model has been normalized by means of the ANP's results. It can be stated as follows: The weights for each of the integer variables were determined via the ANP calculations. The weights were divided by one and allocated to each of the alternatives. Thus, the allocation/distribution process is the normalization for the state variables of the objective function; however, we need no normalization for the control variables in the constraints part.

The empirical example proposed in our research is summarized as follows: Suppose that there exist several obligatory and flexible goals that must be considered in the urban renewal built environment planning and design alternative. There are three major obligatory goals: (1) a total maximum of \$36,730,000 of urban renewal planning and design budget is available to complete all of the ATRs for the alternative, (2) a total maximum of 130 manpower is available to complete all of the ATRs for the urban renewal alternative, and (3) the obligatory or not control variables for each ATR's execution. Each ATR's contribution to planning and design, budgeted cost, and manpower is proportional to the rate of urban renewal alternative production that is currently established. The impact of each of the ATRs for urban renewal built environment planning and design alternative (per unit rate of alternative) on each of these technical requirements is shown in Table VI. Also, we can see that these contributions per unit rate of ATRs are shown in the table, along with the goals.

TABLE VI
COST USAGE AND MANPOWER INFORMATION ON URBAN RENEWAL BUILT ENVIRONMENT PLANNING AND DESIGN ALTERNATIVE

	Urban renewal alternative resource usage (a_{ij})											
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	b_i
Budgeted Cost (0,000)	$0	$0	$2315	$0	$5.6	$9.7	$3.2	$3.2	$1157.5	$771.6	$2315	$3673
Manpower	5	25	20	5	10	15	8	15	20	15	20	130
Obligatory or not	Yes	No	No	Yes	Yes	No	No	No	No	No	No	

It should also be noted that the weight of each ATR in the ZOGP model is an average value obtained from the ANP model calculations of groups of experts.

ZOGP model

Minimize Z =

$pl_1\,(d_1^{+}+d_{13}^{+})$

$pl_2\,(0.1189d_2^{-} + 0.1090d_3^{-} + 0.0851d_4^{-} + 0.0826d_5^{-} + 0.0522d_6^{-} + 0.0707d_7^{-} + 0.0946d_8^{-} + 0.1335d_9^{-} + 0.1098d_{10}^{-} + 0.0785d_{11}^{-} + 0.0651d_{12}^{-})$

Subject to

$2315 X_3 + 5.6 X_5 + 9.7 X_6 + 3.2 X_7 + 3.2 X_8 + 1157.5 X_9 + 771.6 X_{10} + 2315 X_{11} + d_1^{-} - d_1^{+} = 3673$

$5 X_1 + 25 X_2 + 20 X_3 + 5 X_4 + 10 X_5 + 15 X_6 + 8 X_7 + 15 X_8 + 20 X_9 + 15 X_{10} + 20 X_{11} + d_{13}^{-} - d_{13}^{+} = 130$

$X 2 + d_3^{-} = 1$

$X 3 + d_4^{-} = 1$

$X 6 + d_7^{-} = 1$

$X 7 + d_8^{-} = 1$

$X 8 + d_9^{-} = 1$

$X 9 + d_{10}^{-} = 1$

$X 10 + d_{11}^{-} = 1$

$X 11 + d_{12}^{-} = 1$

$X 1 = 1$

$X 4 = 1$

$X 5 = 1$

$X_J = 1$ or 0 $j = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11$

The model given above is solved using LINDO software yielding the following results:

$X 1 = X 2 = X 3 = X 4 = X 5 = X 6 = X 7 = X 8 = X 9 = 1$

$X 10 = 0$ $X 11 = 0$

$d_1^{-} = 178.8, d_2^{-} = 0, d_3^{-} = 0, d_4^{-} = 0, d_5^{-} = 0, d_6^{-} = 1, d_7^{-} = 0, d_8^{-} = 0, d_9^{-} = 0, d_{10}^{-} = 0,$

$d_{11}^{-} = 1, d_{12}^{-} = 1, d_{13}^{-} = 7$

Then, ATRs 1-9, but not 10 and 11, were chosen.

One should note that considering interdependencies in the HOQ and analyzing the design problem from a multi-objective perspective cause different design attributes to be focused on. The combined ANP and ZOGP approach, which aims to quantify the interdependencies and multiple objectives inherent in the design problem in a systematic way, appears to be an effective solution aid.

IV. CONCLUSION

The QFD approach, which enables companies to translate citizen needs to relevant alternative design requirements, is a design tool of vital importance. In this paper, we present a systematic decision procedure to be used in QFD alternative planning, which has been traditionally based on expert opinions. The decision approach aims to consider the interdependence between CNs and ATRs, and the inner dependence within them, along with resource limitations, and design metrics such as extendibility and manufacturability.

In a period of intensifying competition, the interaction of different approaches should be embraced and incorporated within the QFD process in order to realize its full potential. This paper employs a combined ANP and ZOGP approach to incorporate CNs and ATRs systematically into the alternative design phase in QFD. The dependencies inherent in the QFD process are taken into account using the ANP approach. Considering resource limitations and the multi-objective nature of the problem, a ZOGP model is constructed to determine the set of ATRs that will be taken into account in the alternative design phase. The use of ANP weights, resource limitations, and other design metrics in the ZOGP model provides feasible and more consistent solutions.

The application of the decision procedure is shown using an empirical example. The proposed framework adds quantitative precision to an otherwise qualitative decision process. The decision approach presented in this paper can be easily extended to other real-world urban built environment applications of QFD by considering additional resource limitations and design metrics.

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