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Housing refurbishment contractors selection based on a hybrid fuzzy-QFD approach

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ABSTRACT

With low demand for new construction, limited land usage, and being aware of sustainability, the refurbishment market has grown greatly and has become more in demand in the construction industry. Most refurbishment work, however, involves a high level of risk, uncertainty, and coordination, which are likely to cause asymmetric information between contractors and residents in a refurbishment process. Most private refurbishment contractor selections are usually based on word-of-mouth referrals that lack a systematic and objective assessment method. This study proposes a hybrid approach combining fuzzy set theory and quality function deployment (QFD) to establish a housing refurbishment contractor selection model. With this model, residents can select an optimal refurbishment contractor according to requirements. To test the effectiveness of the proposed model, a known multiple criteria decision-making method, PROMETHEE, is applied to compare the results of contractor selections. The result reveals that the proposed hybrid fuzzy-QFD approach can be expected to be successful and has potential for handling multiple criteria decision-making problems.

1. Introduction

The refurbishment industry has received increasing attention and grown hugely in the last decade, because of the change in economic conditions and the emphasis on sustainable development [1]. Global organizations have invested plentiful resources in creating sustainable refurbishment environments [2,3]. Although a refurbishment project is relatively small, in some developed countries, the total turnover of the refurbishment market reaches almost a half of the total construction output [4].

Refurbishment has a heterogeneous nature that requires different specialties to perform well in highly variable conditions and requires knowledge and technique to do well [5]. These kinds of projects are usually characterized by complex, small-scale and highly labor-intensive renovation tasks that are full of risk and uncertainty [6,7]. Some research reveals that one of the severest challenges of refurbishment projects is asymmetric information between contractors and residents in a refurbishment process [8]. Residents with inadequate refurbishment knowledge usually lack the judgment ability on cost, quality and service provided by contractors. Disreputable contractors who propose deceitful cost estimation, unpredicted quality, and unstable service usually affects customers' satisfaction and project performance. Asymmetric information results in the gap between expectation and perception, and it may lead residents to be in vulnerable conditions [9].

A great number of studies have explored how to evaluate construction bidding contractors for new construction projects [10,11]. Only a few efforts, however, have been focused on establishing a contractor selection model in refurbishment projects [12], because most housing refurbishment business comes from word-of-mouth referrals [8]. Some refurbishment jobs are even conducted by unskilled “cow boy” operators, which has multiplied management difficulties [13]. The nature of refurbishment makes it difficult to select an optimal refurbishment contractor. Therefore, an effective and structured contractor selection process for residents needs to be developed.

Quality function deployment (QFD) is a quality management method for converting the customer's needs into design specifications [14]. It brings an opportunity to solve asymmetric information problems between resident's implicit needs (What) and contractor's explicit services (How). To help residents express their preference needs precisely, fuzzy set theory is introduced to combine the QFD, a hybrid fuzzy-QFD approach, to explore the asymmetric refurbishment condition between residents and contractors. By means of a refurbishment contractor selection example, the multiple criteria PROMETHEE methodology is adopted to compare results from the proposed approach to test the effectiveness. It is expected that this innovative approach can make a contractor selection process much

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more useful and the conventional multi-criteria decision-making problems more convincing.

2. Characteristics of the refurbishment industry

Refurbishment projects are usually characterized by complex, small-scale and highly labor-intensive renovation tasks [12]. Special characteristics of housing refurbishment include site-driven works undertaken in an existing building [6], intensified uncertainty [15], long turn-round time [16], and many simultaneously operating workers in a restricted space [17]. These unique characteristics render it more difficult to standardize the delivered service, compared to new construction, and the outcome of the refurbishment performance will be highly dependent on a contractor's capability and experience.

Refurbishment can be categorized as a service industry [8]. Providing what customers expect, such as customized products or services, is a key to reach customer satisfaction in service management. The service quality model has indicated the gap between customers' quality perceptions and suppliers' service delivery [9]. Asymmetric information problems between contractors and residents in a refurbishment process will cause an increase in the service quality gap. To improve customer's satisfaction and contractor's competitiveness, a method for decreasing the gap is crucial for refurbishment projects.

3. Contractor selection

Construction contractor selection and evaluation is always one of the most important critical activities of construction procurement. Various studies have focused on the establishment of selection criteria and the development of selection methods. Contractor selection decisions are complicated by the fact that various criteria have to be considered in the decision-making process [18]. These criteria may have quantitative and qualitative dimensions. Preference for a given contractor is generally assumed to depend on an assessment of the quality, price, capability, and performance that the contractor can provide [19,20]. On the other hand, a vast number of methods have been suggested for supporting contractor selection decisions in construction projects [21]. These studies include the application of artificial intelligence (AI) techniques [22], mathematical programming models [23], and multi-criteria decision-making methods [24]. Some research also proposes the applications of outranking methods, such as ELECTRE and PROMETHEE [25], to explore contractor selection problems. Unlike plentiful studies that have explored contractor selection problems in construction projects, there have been relatively few studies on refurbishment projects. The above-mentioned studies, regarding criteria and methods, may provide insights for establishing a refurbishment contractor selection model.

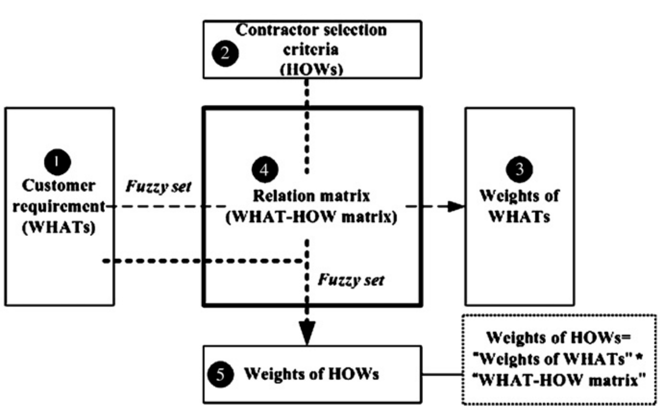

Fig. 1. WHAT–HOW matrix.

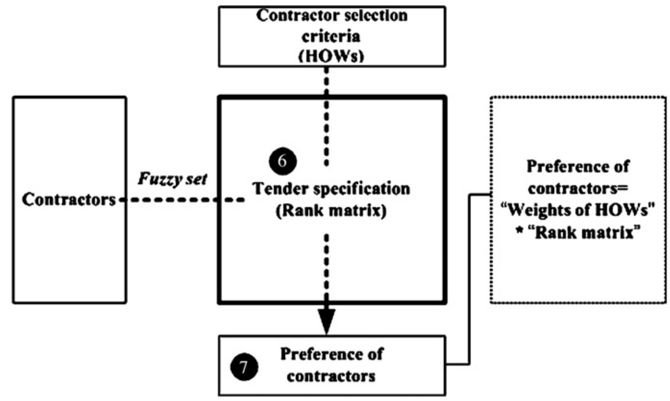

Fig. 2. Rank matrix assessment for rating preference of contractors.

4. Fuzzy-QFD approach for refurbishment contractor selection

4.1. Quality function deployment (QFD)

QFD has been defined as a method for developing a design aimed at satisfying the customer and then translating the customer's demands into design targets and major quality assurance points to be used throughout the production phase [26]. It is a highly effective and structured planning tool to deal with customer demands more systematically. In a refurbishment project, contractors' services may not always satisfy the residents' needs, expectations and quality standards, because refurbishment involves complicated and intensive work that is difficult to integrate. Problems in terms of refurbishment styles, delays due to incomplete designs, misunderstanding of client expectations, rework, etc. are often observed [27]. Some research has demonstrated the benefits of QFD in reducing quality related problems [28]. Therefore, QFD is used in this study for assessing the quality of contractors' services on the basis of the residents' needs.

4.2. An innovative approach: fuzzy set theory based on QFD

Refurbishment usually requires intensive communication between residents and contractors, as well as a complicated process in the design and construction phases. Non-professional residents' inability to analyze the cost and quality of refurbishment may produce difficulty in decision-making and discrepancies between expectations and results [29]. How to effectively extract resident's needs and judge contractors' services is crucial for the success of a refurbishment project.

The fuzzy set theory is widely applied to solve real-life problems that are subjective, vague, and imprecise in nature [30]. To reflect a resident's specific needs in a refurbishment contractor selection, fuzzy set theory is combined with QFD in this study. The linguistic variables are determined and then translated into fuzzy numbers by defining appropriate membership functions. In this study, for example, let F={VL, L, M, H,

Table 1
Resident's requirements and their weights of WHATs

WHATs	DM 1	DM 2	DM 3	Average fuzzy number (LE, ME, UE)	Weight of WHATs (W_{Wi})
Refurbishment quality	VH	VH	M	(6.67, 7.67, 8.67)	0.169
Refurbishment cost	VH	H	VH	(7.33, 8.33, 9.33)	0.184
Transparent information	VH	H	VH	(7.33, 8.33, 9.33)	0.184
Work schedule	VH	VH	H	(7.33, 8.33, 9.33)	0.184
Work integration	H	M	M	(4.67, 5.67, 6.67)	0.125
Service satisfaction	VH	H	M	(6.00, 7.00, 8.00)	0.154

Table 2
Relationship matrix and the weights of HOWs

HOWs																					
WHATs	Performance			Punctuality			Management			Response			Communication			Assurance			Empathy		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
Quality	VH	M	H	VH	H	L	H	VH	L	M	VH	VH	H	H	L	L	VH	H	VH	H	M
	(6.00, 7.00, 8.00)			(5.33, 6.33, 7.33)			(5.33, 6.33, 7.33)			(6.67, 7.67, 8.67)			(4.67, 5.67, 6.67)			(5.33, 6.33, 7.33)			(6.00, 7.00, 8.00)		
Cost	M	H	L	H	M	L	H	M	H	M	VH	H	H	M	L	VH	M	H	VL	L	M
	(4.00, 5.00, 6.00)			(4.00, 5.00, 6.00)			(5.33, 6.33, 7.33)			(6.00, 7.00, 8.00)			(4.00, 5.00, 6.00)			(6.00, 7.00, 8.00)			(6.00, 7.00, 8.00)		
Information	L	M	L	VL	M	M	VH	H	VH	M	H	H	M	M	H	VH	VL	VH	VL	M	H
	(2.67, 3.67, 4.67)			(2.67, 3.67, 4.67)			(7.33, 8.33, 9.33)			(4.67, 5.67, 6.67)			(4.67, 5.67, 6.67)			(5.33, 6.33, 7.33)			(3.33, 4.33, 5.33)		
Schedule	M	VH	M	H	L	H	H	M	H	M	H	M	M	VH	H	H	M	VH	L	L	M
	(5.33, 6.33, 7.33)			(4.67, 5.67, 6.67)			(5.33, 6.33, 7.33)			(4.67, 5.67, 6.67)			(6.00, 7.00, 8.00)			(6.00, 7.00, 8.00)			(2.67, 3.67, 4.67)		
Integration	VL	VL	VL	VH	M	H	L	M	M	VL	M	L	L	M	L	H	M	M	VL	L	VL
	(0.00, 1.00, 2.00)			(6.00, 7.00, 8.00)			(3.33, 4.33, 5.33)			(2.00, 3.00, 4.00)			(2.67, 3.67, 4.67)			(4.67, 5.67, 6.67)			(0.67, 1.67, 2.67)		
Service	L	VL	L	L	L	VL	H	M	H	L	M	L	VH	VH	H	L	M	M	L	L	L
	(1.33, 2.33, 3.33)			(1.33, 2.33, 3.33)			(5.33, 6.33, 7.33)			(2.67, 3.67, 4.67)			(7.33, 8.33, 9.33)			(3.33, 4.33, 5.33)			(2.00, 3.00, 4.00)		
Weight of HOWs	(0.57, 0.74, 0.90)			(0.66, 0.82, 0.99)			(0.91, 1.08, 1.24)			(0.77, 0.93, 1.10)			(0.83, 0.99, 1.16)			(0.86, 1.03, 1.20)			(0.60, 0.77, 0.94)		

VH} be a linguistic set used to express opinions on a group of attributes (VL: very low; L: low; M: medium; H: high; VH: very high).

A whole fuzzy-QFD process developed in this study, as shown in Figs. 1 and 2. Fig. 1 illustrates the basic steps of QFD, including five steps for determining the weights of customer's requirements and criteria: (1) Identify customer's requirements (WHATs): use questionnaires or interviews to gather customer's requirements; (2) Determine contractor selection criteria (HOWs): use literature on supplier selection and expert interviews to determine criteria; (3) Compute the weights of WHATs based on customer's requirements; (4) Build a relation matrix between WHATs and HOWs obtained from different customers: define the correlation score between requirements and criteria; the high score means their high correlation; (5) Compute the weights of HOWs based on relation matrix to determine customer's preference for criteria. Fig. 2 illustrates the other two steps for evaluating the contractor ranks based on the weight of HOWs and WHATs, including: (6) Assess tender characteristics obtained from each contractor's service or specifications; (7) Rank potential contractors according to their performance.

5. Case study

To test the proposed approach, six refurbishment contractors who have conducted housing refurbishment projects were invited to submit their tenders for a simulated project. In this project, three family members, as decision-makers, are required to make their assessments separately according to their preferences for WHATs, HOWs, and contractors. The contractor selection steps are described as follows.

5.1. Identify customer's requirements (WHATs) and their weights

Resident's requirements are identified in advance from a requirement questionnaire carried out by twenty householders who had refurbishment experience in the study year. Housing types for these twenty projects are common apartments or condominium units with floor areas ranging from 81.4 m^2 to 136.2 m^2 and refurbishment budgets from US$39,500 to US$52,400. Although there is some discrepancy among these responses, six major considerations that most householders may consider as high priority in refurbishment are determined: refurbishment quality, refurbishment cost, transparent information, work schedule, work integration, and service satisfaction.

Residents, the decision-makers, need to express an individual preference for each WHAT by means of a linguistic variable. These linguistic variables will be translated into fuzzy numbers. Let F={VL, L, M, H, and VH}, and the fuzzy number of F={(0,1,2), (2,3,4), (4,5,6), (6,7,8), (8,9,10)}. The average fuzzy number is computed by the following equation, and the result of resident's requirements is shown in Table 1.

$$\widetilde{E}i = \frac{1}{k} \otimes \left(\mathrm{LE}_i^k, \mathrm{ME}_i^k, \mathrm{UE}_i^k\right) \quad (1)$$

where $_i$ is the average fuzzy number of the ith WHAT determined by all k decision-makers (k=3 and i=6 in this study); LE_i, ME_i, *and* UE_i denote lower, medium, and upper values of ith WHAT, respectively. The fuzzy set theory that describes a linguistic value sometimes has to be expressed by a crisp value to illustrate the impact levels of quantitative criteria, which means defuzzification. The defuzzification

Table 3
Rank matrix

HOWs																					
Contractors	Performance			Punctuality			Management			Response			Communication			Assurance			Empathy		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
C1	U	M	M	M	U	M	U	U	U	U	M	VU	U	U	M	U	S	M	VS	S	S
	(3.33, 4.33, 5.33)			(3.33, 4.33, 5.33)			(2.00, 3.00, 4.00)			(2.00, 3.00, 4.00)			(2.67, 3.67, 4.67)			(4.00, 5.00, 6.00)			(6.67, 7.67, 8.67)		
C2	S	M	S	S	VS	S	U	M	S	M	VU	VU	VU	U	M	S	VS	M	VS	VS	M
	(5.33, 6.33, 7.33)			(6.67, 7.67, 8.67)			(4.00, 5.00, 6.00)			(2.67, 3.67, 4.67)			(2.00, 3.00, 4.00)			(6.00, 7.00, 8.00)			(6.67, 7.67, 8.67)		
C3	VS	M	L	U	VU	VU	VS	VS	VS	VU	U	VU	U	U	VU	VS	VU	M	S	M	VS
	(4.67, 5.67, 6.67)			(0.67, 1.67, 2.67)			(8.00, 9.00, 10.00)			(0.67, 1.67, 2.67)			(1.33, 2.33, 3.33)			(4.00, 5.00, 6.00)			(6.00, 7.00, 8.00)		
C4	VS	S	U	M	M	U	S	VU	VU	S	S	VS	VU	VU	VU	S	VU	VS	M	U	M
	(5.33, 6.33, 7.33)			(3.33, 4.33, 5.33)			(2.00, 3.00, 4.00)			(6.67, 7.67, 8.67)			(0.00, 1.00, 2.00)			(4.67, 5.67, 6.67)			(3.33, 4.33, 5.33)		
C5	VS	M	S	VS	VS	VS	VS	S	M	M	VU	VU	M	U	M	S	U	S	S	M	VS
	(6.00, 7.00, 8.00)			(8.00, 9.00, 10.00)			(6.00, 7.00, 8.00)			(1.33, 2.33, 3.33)			(3.33, 4.33, 5.33)			(4.67, 5.67, 6.67)			(4.00, 5.00, 6.00)		
C6	U	VU	U	S	VS	VS	M	M	M	U	VU	VU	VU	U	VU	U	S	S	VS	S	S
	(1.33, 2.33, 3.33)			(7.33, 8.33, 9.33)			(4.00, 5.00, 6.00)			(0.67, 1.67, 2.67)			(0.67, 1.67, 2.67)			(4.67, 5.67, 6.67)			(6.67, 7.67, 8.67)		

Table 4
Rank of potential refurbishment contractors

Contractors	Weight of contractors (W_{Cj})			Defuzzification	Normalized	Rank
	LT	MT	UT	W_{Cj}	W_{Cj}	W_{Cj}
C1	2.50	3.92	5.74	4.02	0.73	6
C2	3.48	5.12	7.16	5.22	0.95	2
C3	2.77	4.24	6.08	4.33	0.79	3
C4	2.63	4.11	5.96	4.20	0.76	5
C5	3.70	5.40	7.48	5.50	1.00	1
C6	2.67	4.13	5.98	4.23	0.77	4

equation, based on the Facchinetti et al. [31] approach, is denoted as follows:

$$\mathrm{NF}_i = (\mathrm{LE}_i + 2\mathrm{ME}_i + \mathrm{UE}_i)/4 \tag{2}$$

The weight of each WHAT ($W_{\mathrm{W}i}$) can be computed as follows:

$$W_{\mathrm{W}i} = \mathrm{NF}_i / \sum_{i=1}^{6} \mathrm{NF}_i \tag{3}$$

5.2. Determine selection criteria for contractors (HOWs)

According to some contractor selection literature, an in-depth interview was conducted by twelve experienced experts and contractors to identify appropriate refurbishment contractor selection criteria. The most relevant criteria include past performance, punctuality of delivery, management skills, response time, communication quality, service assurance, and empathy satisfaction. In this simulated project, six contractors were asked to propose their tender strategies regarding service records and specifications to be assessed by residents.

5.3. Build the relationship matrix between WHATs and HOWs and determine the weights of HOWs

Residents can express their preferences, namely correlation score, by using linguistic variables through a matrix questionnaire to assess the relation matrix between WHATs and HOWs, as shown in Table 2. This is an important and basic step for QFD to realize the criteria preference under the impact from requirements. The high score means high correlation between WHATs and HOWs. Fuzzy numbers are used to translate these variables. The preferences of three decision-makers are considered. The determination of the weights of HOWs needs to consider the values of the WHAT–HOW matrix (R_{ij}) and weights of HOWs ($W_{\mathrm{H}j}$). The result after the calculation of fuzzy numbers can be formulated as follows:

$$Rij = (\mathrm{LR}ij, \mathrm{MR}ij, \mathrm{UR}ij) = \frac{1}{k} \otimes \left[\sum_{i=1}^{p} \sum_{j=1}^{q} \sum_{k=1}^{m} \tilde{E}_{ij}^{k} \right] \tag{4}$$

$$W_{\mathrm{H}j} = \sum_{i=1}^{p} \sum_{j=1}^{q} (W_{\mathrm{W}i} \otimes R_{ij}) \tag{5}$$

where R_{ij} is the WHAT–HOW matrix of weighted fuzzy numbers for the ith WHAT and jth HOW determined by all k decision-makers (p=6, q=7, and m=3 in this study).

5.4. Rank potential contractors

According to the service and specification proposed by potential refurbishment contractors, decision-makers use linguistic variables and their relative fuzzy numbers again to evaluate these tenders and then build a rank matrix. Let S={VU, U, M, S, VS} be a linguistic set used to express opinions on a group of attributes (VU: very unsatisfied; U: unsatisfied; M: medium; S: satisfied; VS: very satisfied). Table 3 shows the value of the rank matrix (T_{hj}) for evaluating six contractors. To rank potential contractors, the weight computation is shown as follows and the result regarding the rank of these contractors is shown in Table 4. The higher the weight, the better the contractor.

$$T_{hj} = (\mathrm{LT}_{hj}, \mathrm{MT}_{hj}, \mathrm{UT}_{hj}) = \frac{1}{k} \otimes \left[\sum_{h=1}^{r} \sum_{j=1}^{q} \sum_{k=1}^{m} \tilde{E}_{hj}^{k} \right] \tag{6}$$

$$W_{\mathrm{C}j} = \frac{1}{q} \otimes \sum_{h=1}^{r} \sum_{j=1}^{q} (W_{\mathrm{H}j} \otimes T_{hj}) \tag{7}$$

where T_{hj} is the rank matrix of weighted fuzzy number for the hth contractor and jth HOW determined by all k decision-makers (r=6, q=7, and m=3 in this study). $W_{\mathrm{C}j}$ is the weight of potential contractors.

5.5. Comparison with PROMETHEE methodology

PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations) is a known multiple criteria decision-making and ranking method [32]. To verify the effectiveness of the proposed fuzzy-QFD approach, this study applies PROMETHEE to evaluate the performance of alternative contractors by considering their services and tender specifications. The result of using PROMETHEE is further compared with the result of the proposed approach.

Values of criteria of contractor's tender specification come from the rank matrix of Table 3. The indifference threshold (q) and the

Table 5
Preference function for each pair of contractors

(a,b)	Contractor selection criteria (HOWs)							$P_j(a,b)$	$\pi(a,b)$	(b,a)	Contractor selection criteria (HOWs)							$P_j(b,a)$	$\pi(b,a)$
	H1	H2	H3	H4	H5	H6	H7				H1	H2	H3	H4	H5	H6	H7		
(1,2)	0.0000	0.0000	0.0000	0.0000	0.0667	0.0000	0.0000	0.0667	0.0095	(2,1)	0.6000	1.0000	0.6000	0.0667	0.0000	0.6000	0.0000	2.8667	0.4095
(1,3)	0.0000	0.8667	0.0000	0.3333	0.3333	0.0000	0.0667	1.6000	0.2286	(3,1))	0.3333	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	1.3333	0.1905
(1,4)	0.0000	0.0000	0.0000	0.0000	0.8667	0.0000	1.0000	1.8667	0.2667	(4,1)	0.6000	0.0000	0.0000	1.0000	0.0000	0.0667	0.0000	1.6667	0.2381
(1,5)	0.0000	0.0000	0.0000	0.0667	0.0000	0.0000	0.0667	0.1333	0.0190	(5,1)	0.8667	1.0000	1.0000	0.0000	0.0667	0.0667	0.0000	3.0000	0.4286
(1,6)	0.6000	0.0000	0.0000	0.3333	0.6000	0.0000	0.0000	1.5333	0.2190	(6,1)	0.0000	1.0000	0.6000	0.0000	0.0000	0.0667	0.0000	1.6667	0.2381
(2,3)	0.0667	1.0000	0.0000	0.6000	0.0667	0.6000	0.0667	2.4000	0.3429	(3,2)	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.1429
(2,4)	0.0000	1.0000	0.6000	0.0000	0.6000	0.3333	1.0000	3.5333	0.5048	(4,2)	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.1429
(2,5)	0.0000	0.0000	0.0000	0.3333	0.0000	0.3333	0.0667	0.7333	0.1048	(5,2)	0.0667	0.3333	0.6000	0.0000	0.3333	0.0000	0.0000	1.3333	0.1905
(2,6)	1.0000	0.0000	0.0000	0.6000	0.3333	0.3333	0.0000	2.2667	0.3238	(6,2)	0.0000	0.0667	0.0000	0.0000	0.0000	0.0000	0.0000	0.0667	0.0095
(3,4)	0.0000	0.0000	1.0000	0.0000	0.3333	0.0000	0.8667	2.2000	0.3143	(4,3)	0.0667	0.8667	0.0000	1.0000	0.0000	0.0667	0.0000	2.0000	0.2857
(3,5)	0.0000	0.0000	0.6000	0.0000	0.0000	0.0000	0.0000	0.6000	0.0857	(5,3)	0.3333	1.0000	0.0000	0.0667	0.6000	0.0667	0.0000	2.0667	0.2952
(3,6)	1.0000	0.0000	1.0000	0.0000	0.0667	0.0000	0.0000	2.0667	0.2952	(6,3)	0.0000	1.0000	0.0000	0.0000	0.0000	0.0667	0.0667	1.1333	0.1619
(4,5)	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.1429	(5,4)	0.0667	1.0000	1.0000	0.0000	1.0000	0.0000	0.8667	3.9333	0.5619
(4,6)	1.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	2.0000	0.2857	(6,4)	0.0000	1.0000	0.6000	0.0000	0.0667	0.0000	1.0000	2.6667	0.3810
(5,6)	1.0000	0.0667	0.6000	0.0667	0.8667	0.0000	0.0000	2.6000	0.3714	(6,5)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0667	0.0667	0.0095

Table 6
Net flow of each contractor

	C1	C2	C3	C4	C5	C6	$\Phi^+(a)$
C1	–	0.0095	0.2286	0.2667	0.0190	0.2190	0.7429
C2	0.4095	–	0.3429	0.5048	0.1048	0.3238	1.6857
C3	0.1905	0.1429	–	0.3143	0.0857	0.2952	1.0286
C4	0.2381	0.1429	0.2857	–	0.1429	0.2857	1.0952
C5	0.4286	0.1905	0.2952	0.5619	–	0.3714	1.8476
C6	0.2381	0.0095	0.1619	0.3810	0.0095	–	0.8000
$\Phi^-(a)$	1.5048	0.4952	1.3143	2.0286	0.3619	1.4952	–
Net flow	−0.7619	1.1905	−0.2857	−0.9333	1.4857	−0.6952	
Rank	5	2	3	6	1	4	

$\Phi^+(a)$ means leaving flow; $\Phi^-(a)$ means entering flow.

preference threshold (p) are set to 0.5, and 4, respectively. For each pair of contractors, a preference function, $P_j(a,b)$ that represents preference level of a to b on criterion and $P_j(b,a)$ that represents preference level of b to a on criterion is established as shown in Table 5. Aggregated preference indicator, $\pi(a,b)$ and $\pi(b,a)$, can be also computed as shown in Table 5. Finally, the concept of *flow* is introduced to express the ranks of alternatives. The result of the net flow computation is shown in Table 6.

Compared with the result of the proposed fuzzy-QFD approach, the ranks achieved by adopting PROMETHEE methodology have very slight differences. The first four preferred contractors, C5 > C2 > C3 > C6, are the same for the both methods. Although PROMETHEE methodology is a famous and conventional multi-criteria decision-making method that can effectively select and evaluate suppliers [21], this method, however, has some limitations in defining appropriate criteria and their assessment values. A complicated comparison of each pair of contractors in each criterion also takes much judgment time. This case study reveals that the proposed approach is more effective in judgment time, procedures, as well as, is more objective in determining the preference of WHATs and HOWs.

6. Conclusions and suggestions

Refurbishment has a heterogeneous nature that requires different specialties and management skills to perform well in highly variable conditions. Traditional housing refurbishment contractor selection procedures are controversial because most of them are usually based on word-of-mouth referrals or resident's intuitive judgments. This may easily lead to a vicious cycle of asymmetric information if, unfortunately, a resident is not able to select an appropriate contractor to conduct a complicated refurbishment project.

The introduction of QFD supports the relation assessment for residents' refurbishment requirements (WHATs) and contractors' specifications (HOWs). By using the fuzzy set theory, residents can select a satisfactory contractor even when they have indistinct needs and vague preferences. Traditional application of QFD did only determine, or realize, the relation between WHATs and HOWs. This study has extended the implication of QFD to present an innovative approach for solving the refurbishment contractor selection problems. Compared with conventional multi-criteria decision-making methods, the result of the case study using the hybrid fuzzy-QFD approach has made a successful experiment and demonstrated potential as an alternative analytic tool with less judgment time and more objectivity. The disadvantages of time and objectivity are usually regarded as limitations in traditional multi-criteria decision-making methods.

The purpose of this study, however, is not to judge nor validate the application of PROMETHEE methodology. On the contrary, this study pays more attention to establishing an alternative analytic structure well suited to different kinds of multi-criteria decision-making problems. Some extensions and improvements need to be accomplished from this approach. The approach can be extended to explore various multi-criteria decision-making issues such as selection among alternatives or project assessment, if the variables or criteria can be modified with flexibility to conform to the practical needs. How to ensure the completeness of judgment information, such as explicit service or tangible specifications offered by contractors, to rationalize the approach will be an improvement challenge. The number of questionnaire samples may also influence the way of determining WHATs, HOWs and their computing results. It is expected that there will be a steady improvement, based on the core of the proposed approach, in providing more samples and sufficient information in the further research to make the contractor selection more convincing.

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