International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

An A/E Pre-Qualification Model Based on the Quality Function Deployment Method

Ali Ali Shash[1], Feras Saleh Ajairi[2]
[1]Construction Engineering and Management Department, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia
[2]Construction Engineering and Management Department, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia
E-mail: [1]aashash @ kfupm.edu.sa, [2]g201701170 @ kfupm.edu.sa

Abstract**—** *Choosing a suitable architectural and engineer consultant (A/E) for a construction project is a very crucial decision and significant endeavour to archive an owner's project requirements (quality, time, and cost). The prequalification of A/Es for every project is considered a crucial step in identifying a collection of eligible A/Es, which is required for post-qualification steps and further considerations. Unfortunately, the current prequalification systems do not pay considerable attention to an owner's project requirements, mostly focusing on A/Es selection criteria and yield unsatisfactory results. Unfortunately, there is inadequate research to present an A/E prequalification model considering an owner's project requirements. The Quality Function Deployment (QFD) method is used to develop a model that considers an owner's project requirements, and an A/E's capabilities. The developed model has proven its effectiveness and reliability through its application in selecting appropriate A/Es for industrial, engineering, and road construction projects. This paper has a practical value to owners worldwide, as selecting the appropriate A/E would result in better project performance. Besides, it contributes to the book of knowledge in modelling A/E prequalification process and applying the QFD method in the construction industry.*

Keywords**—** *A/E selection, prequalification, quality function deployment (QFD), Saudi Arabia.*

I. INTRODUCTION

Architectural and Engineering offices (A/E) play a significant role in the development of construction projects where they are primarily responsible for converting a project owners' ideas to project documents (drawings, specifications, conditions of contracts) that aligns with their objectives including cost, time, and quality. An owner, when undertakes a construction projects, makes crucial decisions over the life of the project development. The performance in a construction project is often associated with successful owner's decisions. Selecting the most appropriate A/E is one of the most critical decisions that an owner makes and the more appropriate the selection is, the higher the chances the owner will achieve his objectives.

Owners follow different available methods to help them in their A/Es election decisions. The available methods are classified into direct or comparative. In the direct selection, an owner considers and approaches a single A/E on the basis of reputation, personal acquaintance or some personal recommendation. In the comparative selection, an owner considers and rank several candidates based on established qualification parameters and select the highly ranked A/E. The comparative approach is predominant as it generates a broad pursuit for the best A/E to a particular construction project opportunity (Haviland, 2000). The comparison could be based on one tangible or multi tangible and intangible criteria. Design competition and service fee are mostly used as single criterion. The design competition allows the owner to make the selection decision based on available state of the art knowledge and the generated prototypical ideas (AIBC, 1998). The price criterion is more common where an owner considers and selects an A/E based on the price to be charged for the service. The multi-intangible method is the Quality Based Selection (QBS), which is a process that enables the project owner to obtain the services of a highly qualified design professional at a fair and reasonable cost (Consulting Engineers Council of Pennsylvania (CEC/PA), 2000). This is said to be the most widely endorsed legal method for selecting a design professional by overseas public owners (Consulting Engineers Council of Delaware (CEC/DE), 2000) and is recommended by the Australian Council of Building Design, the Architects Council of Europe (ACE), Association of Japanese Consulting Engineers and the American Public Works Association and various other organizations around the world (CIC, 2014). Although the recently developed selection processes have attempted to consider more criteria, the basis for making decision remains judgmental.

Despite the currently available different A/E selection methods, the majority of projects suffer from delays and cost overrun caused by the project documents. Assaf and Al-Hejji (2005) reports that 70% of projects evaluated experienced a time overrun, where the quality of the A/E services was one of the major sources of project delay. Assaf et al. (2017) indicated that design errors were the second highest factor causing project delays in large projects in Saudi Arabia. Habash (2019) reported that project documents including drawings, specifications, contract conditions, and addenda have significant contribution to the frequency of current disputes in the construction industry. These statistics suggest that the current A/E selection methods are not effective in selecting competent A/Es to provide the proper services to the owner.

The primary purpose of the study is to help the owner select the best A/E based on fulfilling the project constraints in relation to the A/E selection criteria. The objective of this study is to develop a new A/E pre-qualification model employing the quality function deployment (QFD) method considering both the project owner's requirements and the A/E abilities.

II. LITERATURE REVIEW

A/E Selection Systems

Babatunde et al. (2012) define the procurement method as "as the management of the total process involved in construction project delivery" and emphasize that the procurement methods optimize all project delivery parameters, namely, time, cost, and quality. Assaf et al. (2017) emphasize the selection process's criticality for an appropriate A/E. Selecting an inappropriate A/E harms the project objectives during construction and operation. Thus, inappropriate A/Es should be filtered out to eliminate or reduce the selected A/E's adverse effects on the project objectives. Boer et al. (2001) recommend the first step is to determine a set of acceptable A/Es while possible subsequent steps serve to reduce the number of A/Es to the most appropriate ones.

Price-based, sole-source, and quality-based systems are used to select A/Es. The price-based selection is defined as selecting a firm for specified consulting services based on the project value and related cost (Elwardani et al. 2006). The price-based selection system entails an owner to select an A/E with the lowest design fee. Kasma (1987) suggested selecting A/Es based on the design fee rather than on qualification. Municipalities' managers in Sweden are generally satisfied with selecting A/Es based on design fees (Sporrong, 2011). Owners who measure competitiveness based on price believe that they should not pay more for a service that could cost less (Christodoulou et al., 2004). However, the selection of consultants based on price alone is problematic and might cause project delays and cost overrun (Ng et al., 2001), is not appropriate for the vision of services (Gronroos, 1984; Latham, 1994), and drives fee levels down leading to a reduction in the quality of services involved (Day, 1998). Besides, the price-based selection leads to failure because the prepared and submitted fee is baseless, as the scope and nature of the services required are not well defined (Peck, 1998). The sole source selection entails an owner to selects an A/E based on personal knowledge, references, and reputation.

The quality-based selection (QBS) is the dominant approach to select A/Es and focuses on the deliverables' quality, just as the name suggests. Chinowsky and Kingsley (2009) emphasized the importance of selecting A/Es based on qualifications rather than on the lowest price. Brook Act originated QBS in 1972 in the USA. Nowadays, QBS has seen widespread use throughout the United States, Asia, Canada, Europe, and Canada. Shelton (2018) claimed that QBS has a considerable number of advantages, including cost-growth, schedule-growth, unit cost, project intensity, construction speed, perceived risk in projects, project complexity, excessive bureaucratic systems, level of overall project quality, administrative waste, and proposal writing costs. Besides, the level of innovation over other competitive procurement methods involves the price of selecting A/E. The QBS process involves evaluating numerous predetermined A/E capabilities (criteria), which are considered with equal or different weighted importance.

We were able to identify 27 criteria from the literature, of which 13 criteria were found, through intensive analysis, highly essential to define an A/E's capabilities, and significantly influence OPR. (Note: The study on PQC has been submitted for publication and currently under review). Under this method, the capabilities of each A/E are subjectively measured and totaled. The A/Es are, then, ranked according to their corresponding total capabilities scores, and the owner selects the A/Es with top scores for price negotiation. QBS is also used to select Design-Build contractors through the Best value, the fixed price/best technical value, and the weighted criteria selections. The best value process involves a prequalification of the bidders based on technical criteria, after which the owner selects the bidder with the best value (Elwardani et al. 2006). The fixed price/best technical value is mainly used with a design-build delivery system. The weighted criteria combine the technical and commercial proposals in an evaluation and comparison matrix (Molenaar and Gransberg, 2001). Then, the selection is as per the best value of money that meets the project constraints.

The literature presents numerous models for A/Es prequalification based on QBS. Unfortunately, there are inadequate researches addressing an A/E prequalification model with consideration of the OPR. Potter and Sanvido (1995) developed a model consisting of several constraints: economic, political, technological, corporate policy, labor, and personnel and legal aspects for A/E prequalification and selection. Cheung et al. (2002) and Al-Besher (1998) developed an AHP model for selecting A/Es in Hong Kong and Saudi Arabia, respectively. Martinovic and Delibasic (2014) developed and AHP-IBA model to select consultants for the SAP ERP project. Ling (2002) developed a conceptual model for the selection of A/Es in Singapore. The model depends primarily on "A/E's problem-solving ability and project approach," "A/E's speed in producing design drawings," and "the A/E's level of enthusiasm in tackling a difficult assignment." Ling (2003) developed a multi-decision-making model based on 34 critical attributes for selecting A/Es. The essential attributes are "good knowledge of economical designs and constructability," "producing designs which have functional quality," "gaining adequate job experience," and "producing design drawings and obtaining statutory approvals speedily." Ng and Chow (2004) developed a framework to determine the critical criteria for the pre-selection of A/Es in Hong Kong. A multi-criteria model was then developed to score A/Es' capabilities. A/Es with acceptable scores are the only ones invited to bid for projects.

Chow and Ng (2007) used the fuzzy gap analysis model to evaluate A/Es' performance to select the A/E with the highest performance. Unfortunately, all the available A/E selection methods are based on qualification criteria which are evaluated subjectively and do not consider OPR. Bowen (1999) stated, "Once client objectives have been established, a fundamental aspect of the procurement process which requires early attention is the selection of the most appropriate organizational structure (procurement system) for the design and construction of the project. Therefore, OPR shall be defined for the appropriate procurement of A/E services. This study employs the QFD to include the voice of the owners into the selection of A/Es.

Quality Function Deployment (QFD)

QFD was born in the Mitsubishi Heavy Industries shipyards during the 1960s to improve and freeze ships' initial designs. Shortly, QFD was used by major Japanese manufacturing industries. It was about 15-20 years after Japan when QFD entered as a methodology in the USA. Nowadays, QFD is used by the majority of the major companies in Japan (Ghiya et al., 1999) and is a crucial development tool for products and services in many developed countries.

Cohen (1995) defined QFD as 'a method for structured product planning and development, which enables the development team to realize the customers' wants and needs and evaluate each product or service capability systematically in terms of its impact on meeting those needs.' QFD is a system to translate and plan the Voice of the Customers (VoC) into the quality characteristics of products, processes, and services to reach customer satisfaction. In other words, QFD focuses on prioritizing the customers' needs to produce competitive quality products in the design phase, using a series of matrices and other techniques (Ahmed et al., 2003). QFD comprises building one or more matrices known as 'quality tables.' The house of quality (HOQ), which is the primary tool of QFD, displays the voice of the customer (VoC) or the customer needs against the technical responses to meet them. Figure 1 illustrates the matrices of the HoQ, each of which holds information specific to a part of the QFD procedure. The suggested order, shown by letters A to F, should be followed during the process (Delgado-Hernandez et al., 2007). Matrix A contains a list of customers' wants. Each item is assessed through a comparison with other competitors. The results are then inserted into matrix B. Matrix C contains the information necessary to transform the customer expectations into technical terms. The correlation between each customer want and each technical response is inserted into matrix D. The 'roof' (matrix E) considers the extent to which technical responses support each other. The prioritization of technical characteristics, the information concerning the competition, and technical targets go into matrix F (Cohen, 1995; Delgado-Hernandez et al., 2007).

Use in the Construction Industry

Many industries worldwide, excluding the construction industry, benefit from the QFD application in developing many products and services (Chan and Wu, 2002). Unfortunately, QFD has not been widely acknowledged in the construction industry, where only 7% of D/B contractors and 10% of architects and engineers were familiar with QFD (Pheng and Yeap, 2001). Besides, QFD is not a recognized or requested tool in the practices of government, institutions, nonindustrial corporations, and other private clients in the USA (Oswald and Burati 1993). Delgado-Hernandez and Aspinwall (2007) revealed that QFD was still 'little known' in the UK construction sector. They found, through a survey, that only 18% of the surveyed respondents were aware of its existence. Therefore, the literature is scarce concerning QFD applications in the construction industry and in selecting A/E in particular, which has probably restricted its widespread application (Delgado-Hernandez et al., 2007).

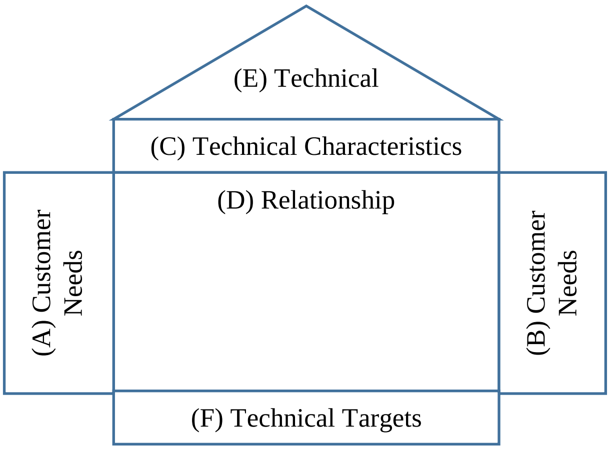


Figure 1: House of Quality (HOQ)

Several researchers utilized QFD in their researches in the construction industry. In the United States, Mallon and Mulligan (1993) applied QFD to the design and construction process of renovating a hypothetical personal computer workroom's facilities. The study concluded that QFD could be successfully implemented if a company-wide commitment to quality and improvement is in place. Eldin and Hikle (2003) performed a pilot study to implement QFD in the design of a construction project in the US. They prepared a conceptual design for a modern large-size classroom for college students. In the United States, Arditi and Lee (2003) and Lee and Arditi (2006) used QFD to describe a tool to measure a design-build firm's quality performance at the corporate, project, and product levels. Cariaga et al. (2007) used QFD and other functional analysis techniques to present a hybrid framework for eliciting and evaluating design alternatives. In Malaysia, Abdul-Rahman et al. (1999) applied QFD to several cases in the construction industry, with a particular emphasis on a low-cost housing scheme. They exhibited the benefits of adopting QFD for different aspects of reliability from the customer perspectives, considering quality, cost, and time for low-cost housing. Their efforts led to identifying the most critical characteristics in customer satisfaction, which could be included in an improvement plan for future projects. Abdul-Rahman et al. (1999) used QFD to identify the essential characteristics, which could be included in an improvement plan for future projects to satisfy customers on a low-cost housing scheme in Malaysia. Ignatius et al. (2016) provided an integrated structure for assessing green buildings in Malaysia realistically based on stakeholders' fuzzy preferences. They used the analytic network approach (ANP) to evaluate the correlation matrices in a quality function deployment (QFD) framework. In the UK, Kamara et al. (2000) proposed the HOQ to be applied to process the customer requirements during the early stages of a project. Afterward, they reported a hypothetical example showing how the tool could be applied in constructing a family house. Delgado-Hernandez et al.

(2007) used QFD to identify and analyze customer requirements for a new children's nursery school in the UK. Ahmed et al. (2003) explored the applicability of QFD in the planning process of a civil engineering capital project in Hong Kong by developing a QFD model using a template for the process. They finally considered that QFD could be successfully used in the capital project planning process. Moreover, Yang et al. (2003) combined QFD with knowledge management to set up a system that can support the creation of constructible designs.

The fuzzy theory was employed to manage the vagueness of the design inputs. Dikmen et al. (2005) examined the applicability of QFD as a strategic decision-making tool after the construction stage of a housing project. They used QFD to determine the best marketing strategy and afterward, to make a comparison between the performances of different competitors, and to transfer the experiences gained from the current project to the forthcoming ones. Jafari (2013) developed a contractor prequalification model that employs the quality function deployment (QFD) method and considers both OPR and the A/E's abilities. Wee et al. (2017) developed a QFD model for a modular plant-room for advanced offsite construction. In the research done by Delgado-Hernandez et al. (2007), the HOQ matrix was constructed and used to prioritize both customer needs and technical characteristics to design a new nursery school in the UK. Juan et al. (2009) proposed a hybrid approach combining the fuzzy set theory and QFD to establish a housing refurbishment contractor selection model. Recently, Yasamis-Speroni et al. (2012) introduced a contractor quality performance evaluation model based on the QFD method to measure pavement contractors' quality performance. This research employs the QFD method to involve the 'voice of the project owners' by prequalifying the A/E in the construction industry. As Cariaga et al. (2007) emphasized, QFD is not a solution, but rather a systematic process towards finding the customer, thereby achieving the more satisfied customer.

III. A/E SELECTION MODEL BASED ON QFD

QFD is used in this research to include the 'voice of the project owners' through the prequalification of A/Es. The proposed model applied the classic HOQ with some revisions and alterations. The classic HOQ matrices, which have been used in the model, are provided here: matrix A as the project requirement OPR and expectations; matrix B as the A/E characteristics and abilities; matrix C as the strength of each A/E characteristic to achieve each project requirement; and matrix D as the process matrix. The elements of the proposed model are presented in Figure 2. The process of the proposed model for the prequalification of A/E involves five steps.

Step 1: identifying the data matrix elements

The data matrix in Figure 2 contains all the information required to develop the proposed model and includes the following items:

- WHATs: include OPR and expectations that an A/E should achieve, such as preparing design documents that meet the owner's planned time, cost, and quality.
- HOWs: include the A/Es' abilities to comply with the OPR, such as having technical experience, design quality, skillful architects and engineers, construction estimation quality, and other prequalification criteria.
- IHj: the weight of importance of each HOW.
- Sij: the strength of the interrelationship between each WHAT and each HOW. Sij reflects how much each HOW (A/E capability) can influence the achievement of each WHAT (project requirement). Cohen (1995) suggested a scale ranging from 1 to 9 where 1 for possibly linked, 3 for moderately linked, and 9 for strongly linked. Arditi and Lee (2003) and Lee and Arditi (2006) proposed a normalized scale ranging from 0 to 1 for no interrelationship to the highest interrelationship, respectively. For the model in this study, the latter scale is employed.

		Engineering Office Abilities				
		how_1	how_2	how_3	…	how_j
		IH_1	IH_2	IH_3	…	IH_j
Project Requirements	$what_1$	S_{11}	S_{12}	S_{13}	…	S_{1j}
	$what_2$	S_{21}	S_{22}	S_{23}	…	S_{2j}
	$what_3$	S_{31}	S_{32}	S_{33}	…	S_{3j}
	…	…	…	…	…	…
	$what_i$	S_{i1}	S_{i2}	S_{i3}	…	S_{ij}

Figure 2: QFD Model

The first step in QFD is developing a data matrix consisting of Owner Project Requirements (WHAT), the selection Prequalification Criteria (HOW) along with their importance weights of the selection (IHj) that an owner considers. Moreover, the data matrix requires the level of association between the PQC and OPR. The influence of the selection PQC (HOW) on project OPR (WHAT) measures the relationship between those two variables and designated Sij in the data matrix. Therefore, the QFD model development mandates the collection of two different data sets concerning the identification of PQC (HOWj) and their level of importance (IHj) to the project owner, and the level of influence (Sij) of the identified criteria on each OPR (WHATi) including quality, time, and quality which are widely accepted criteria for project success (Westerveld, 2003; Wang and Huang, 2006; Tabish and Jha, 2012; Alzahrani and Emsley, 2013). We were able to identify, through Terrel's Transformation Scores (TTS) and Coefficient of Variation (CV), 13 critical PQC (IHj) with significant importance to selecting A/Es and significant influence on OPR (Sij). The participants provided numerical scoring expressing their opinions on the importance of PQC for the selection of A/Es and the influence of the PQC on OPR. Terrel's transformation indices (TTS) and Coefficient of Variation (CV) of each criterion were calculated. According to Toh et al. (2012), PQC with TTS indices of 65% and above are considered critical in the A/E selection while criteria that have TTS indices below 65% are regarded as less critical. The results indicate that 17 criteria have obtained a transformed score between 65% and 95% and CVs ranging from 10% to 33%, indicating that the owners with a high level of agreement consider those 17 factors critical for selecting A/Es. The owners highly agree

(CV ranges from 27% to 59%) that the remaining 11 criteria are not critical (TTS ranges from 33% to 63%). The results indicate that 10, 11, and 9 identified PQCs are found to critically influence the quality, time, and cost requirements, respectively. The critical PQC influencing quality, time, and cost requirements have obtained a TTS between 73% and 88%, 65% and 85%, and 66% and 77%, respectively. CVs show that the variation of responses on PQC influencing OPR is relatively low, suggesting a relatively high level of agreement among the owners in rating PQC. All the 10, 11, and 9 influencing PQC have CVs ranging from 15% to 29%, 20% to 29%, and 25% to 30%, respectively.

The selection criteria, the importance of selection criteria, and the influence of selection criteria on the project quality, time, and cost requirements are extracted from Shash and Ajairi's (2021) published paper and presented in Tables 1 and 2. They are used to develop the QFD model.

Table 1: QFD Model Selection criteria (HOW) and Importance Weight (IHj)

	Criteria	**TTS**	**IHj***
1	Technical Experience	95	9.00
2	Design quality	88	8.33
3	Staff Quality	88	8.33
4	Past Performance	86	8.16
5	Key Designer	80	7.60
6	Design service Time	86	8.16
7	Construction estimation quality	80	7.60
8	Project Engagement	86	8.16
9	Bid Quality	88	8.33
10	Project Context	81	7.67
11	Number of years in business	68	6.44
12	Specialty designing services	65	6.16
13	Current Workload	65	6.16
	Total	1056	10.0

*IHj = TTSj/SUM TTS

Table 2: QFD Model Selection criteria (HOW) Influence on Project Constraint

Criteria	**Project Requirements TTS**		
	Quality	**Time**	**Cost**
Technical Experience	0.88	0.85	0.75
Staff Quality	0.81	0.76	0.76
Bid Quality	0.74	0.56	0.55
Design quality	0.85	0.80	0.77
Project Engagement	0.75	0.75	0.64
Design service Time	0.76	0.82	0.77
Past Performance	0.79	0.79	0.70
Project Context	0.73	0.76	0.66
Key Designer	0.77	0.74	0.69
Construction estimation quality	0.76	0.71	0.66
Current Workload	0.59	0.68	0.54
Number of Years	0.61	0.57	0.46
Specialty design	0.60	0.60	0.51

The above data are used to develop the data matrix, which is used as the source for evaluating A/Es during the selection process. The data matrix, shown in Figure 3, presents the data for the most appropriate A/Es for owners. This matrix is used as the reference for the evaluation and selection of A/Es for future projects.

Step 2: identifying the process matrix elements

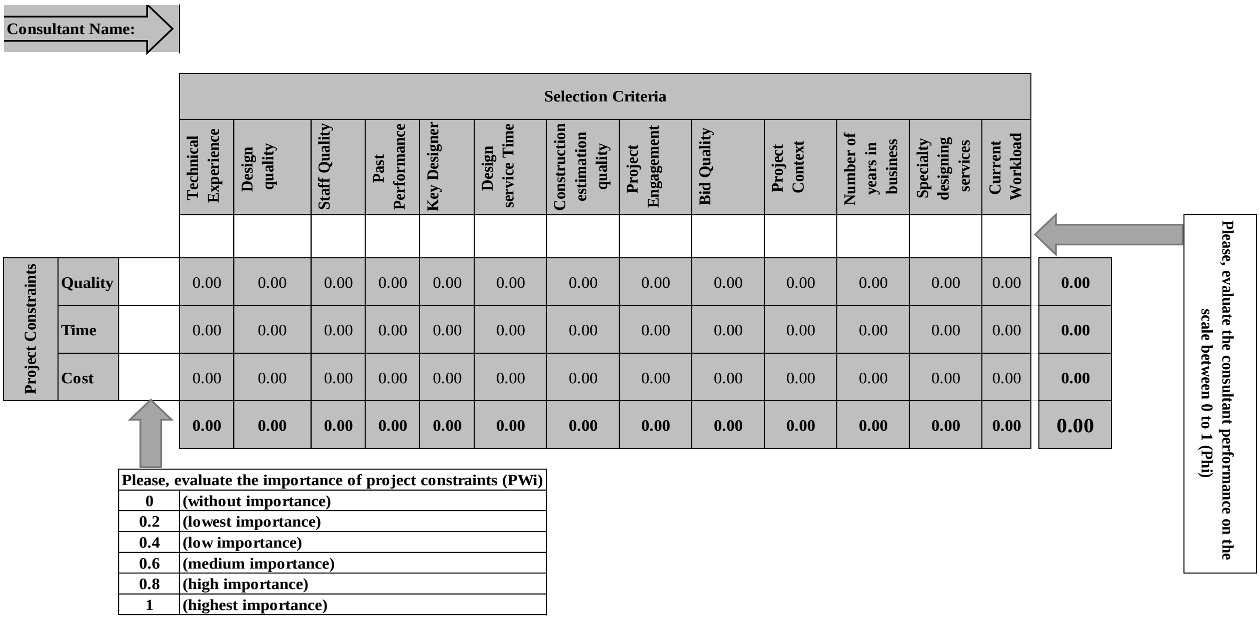
The second step in the QFD is to develop the process matrix consisting of, as shown in Figure 4, an owner's inputs, including the weight of importance of OPR to the owner (PWi) and the evaluations of A/Es capabilities (PHi). Each A/E is evaluated in a separate process matrix.

		Prequalification Criteria (PQC)												
		Technical Experience	**Design quality**	**Staff Quality**	**Past Performance**	**Key Designer**	**Design service Time**	**Construction estimation quality**	**Project Engagement**	Bid **Quality**	**Project Context**	**Number of years in business**	**Specialty designing services**	**Current Workload**
		0.90	**8.33**	**8.33**	**8.16**	**7.60**	**8.16**	**7.60**	**8.16**	**8.33**	**7.67**	**6.44**	**6.16**	**6.16**
Project Requirements (OPR)	**Quality**	0.88	0.85	0.81	0.79	0.77	0.76	0.76	0.75	0.74	0.73	0.61	0.60	0.59
	Time	0.85	0.80	0.76	0.79	0.74	0.82	0.71	0.75	0.80	0.76	0.57	0.60	0.68
	Cost	0.75	0.77	0.76	0.70	0.69	0.77	0.66	0.64	0.55	0.66	0.46	0.51	0.54

Figure 3: Data matrix for the selection of the most appropriate A/E

			Engineering Office Abilities					
			HOW_1	HOW_2	HOW_3	…	HOW_j	
			PH_1	PH_2	PH_3	…	PH_i	
Project Requirements	WHAT_1	PW_1	R_{11}	R_{12}	R_{13}	…	R_{1j}	PSW_1
	WHAT_2	PW_2	R_{21}	R_{22}	R_{23}	…	R_{2j}	PSW_2
	WHAT_3	PW_3	R_{31}	R_{32}	R_{33}	…	R_{3j}	PSW_3
	…	…	…	…	…	…	…	…
	WHAT_i	PW_i	R_{i1}	R_{i2}	R_{i3}	…	R_{ij}	PSW_i
			PSH_1	PSH_2	PSH_3	…	PSH_j	PS

Figure 4: Process Matrix



Consultant Name:

Project Constraints			Technical Experience	Design quality	Staff Quality	Past Performance	Key Designer	Design service Time	Construction estimation quality	Project Engagement	Bid Quality	Project Context	Number of years in business	Specialty designing services	Current Workload	
Project Constraints	Quality		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	Time		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	Cost		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
			0.00	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Selection Criteria

Please, evaluate the consultant performance on the scale between 0 to 1 (Phi)

Please, evaluate the importance of project constraints (PWi)	
0	(without importance)
0.2	(lowest importance)
0.4	(low importance)
0.6	(medium importance)
0.8	(high importance)
1	(highest importance)

Figure 5. QFD Model Process Matrix

Step 3: Calculating the Point scores (Rij)

The third step is to use the information obtained from step 1 and 2 to calculate the point score (Rij) for each intersection between WHATs and HOWs is calculated using Equation1:

$$Rij=PWi \times (IHi \times PHi) \times Sij \qquad (1)$$

where Rij is the point score for the intersection between WHATi and HOWj; PWi is the status of WHATi; IHj is the weight of importance of HOWj; PHj is the status of HOWj; and Sij is the strength of the interrelationships between WHATi and HOWj (from the data matrix).

Step 4: Calculating prequalification scores (PSW) and (PSH)

The fourth step is to calculate the prequalification score for WHATi (PSWi) and HOWj (PSHj) using equations 2 and 3.

$$PSWi = \sum_{j=1}^{n} Rij \ \ for\ 1 \leq i \leq m) \qquad (2)$$

$$PSHj = \sum_{j=1}^{n} Rij \ \ for\ 1 \leq i \leq n) \qquad (3)$$

The summation of the horizontal point scores (PSWi) designates the desired prequalification score of the corresponding OPR. The summation of the vertical point scores (PSHj) presents the prequalification score of HOWj to achieve the required OPR.

The A/Es prequalification scores are calculated using equation 4.

$$PS = \sum_{j=1}^{m} PSWi = \sum_{j=1}^{n} PSHj \qquad (4)$$

Step 5: Calculating the A/Es prequalification indices (API)

The fifth step is to calculate the A/E prequalification index (API) for each A/E using the following equation.

$$API = PS/MaxPS \qquad (5)$$

where MaxPS is the maximum score of prequalification that an A/E can achieve, in which the entire status of HOWs are rated at their highest value. To calculate the MaxPS, Equations 3, 4, 5, and 6 should be used via the replacement of PHj by 1 (the highest score). An A/E with the highest API is the first choice for selection.

IV. MODEL APPLICATION AND VALIDATION

Three owner organizations were recruited to apply the developed model in selecting A/Es for recently completed projects. The owners were requested to provide the names of A/Es, which were invited to provide the names of A/Es, which were invited to compete for the design of the projects that are under consideration, the details of their A/E selection systems. They were also requested to provide their importance levels of OPR and evaluate the thirteen capabilities of the A/Es. Tables 3 and 4 present the owners' inputs, which were used in the developed model to select the same.

Table 3: Project Requirement

Project Requirements (OPR)	**Importance of Project Requirements (PWi)**		
	Owner 1	Owner 2	Owner 3
Quality	0.8	0.8	0.8
Time	1.0	1.0	0.6
Cost	0.4	0.6	1.0

A detailed qualitative analysis was performed to show the differences between the outcomes of both systems. compete for the design of the projects that are under consideration, the details of their A/E selection systems.

QFD model validation: Owner 1

Owner 1 is a private manufacturing company in Dammam, Saudi Arabia, employing more than 2500 employees and awards several construction projects annually with an average value exceeding SR100 million. The owner employs the quality-based selection (QBS) system for selecting A/Es. The owner provided for the study a mega industrial plant project worth more than SR100 million, which was built through the design-bid-build delivery system. The owner indicated that they invited three A/Es designated A, B, and C to compete for the above project and evaluated them based on technical experience, past performance, key designer, bid quality, project context, and specialty designing services. They did not consider design quality, staff quality, design service time, and construction estimation quality. The owner's QBS directed him to award the design contract to consultant C for more than SR4 million. The owner asserted that OPR as follows: time is extremely high important (PW=1), quality is highly important (PW=0.8), and time is important (PW=0.4) where the project could be extended to an acceptable limited not to exceed six months.

Table 4: Owners' selection criteria

Selection Criteria	**Owner 1**			**Owner 2**			**Owner 3**		
	Consultants Evaluation			**Consultants Evaluation**			**Consultants Evaluation**		
	A	B	C	KA	DH	AM	E	F	G
Technical Experience	0.70	0.95	0.85	0.90	0.80	0.80	0.80	0.75	0.90
Design quality	0.65	0.90	0.50	0.40	0.70	0.70	0.90	0.80	0.85
Staff Quality	0.65	0.90	0.50	0.90	0.70	0.60	0.75	0.60	0.75
Past Performance	0.65	0.90	0.75	0.90	0.80	0.70	0.70	0.75	0.80
Key Designer	0.65	0.90	0.90	0.90	0.80	0.80	0.80	0.70	0.90
Design service Time	0.70	0.95	0.20	0.80	0.90	0.90	1.00	0.80	0.85
Construction estimation quality	0.40	0.80	0.60	0.30	0.80	0.80	0.90	0.85	0.95
Project Engagement	0.90	0.70	0.70	0.50	0.90	0.90	0.60	0.60	0.80
Bid Quality	0.90	0.85	0.90	0.70	0.70	0.80	0.75	0.70	0.85
Project Context	0.35	0.70	0.90	0.90	0.60	0.70	0.80	0.65	0.80
Number of years in business	0.65	0.90	0.85	0.90	0.60	0.60	0.50	0.60	0.85
Specialty designing services	0.85	0.50	0.35	0.90	0.80	0.70	0.70	0.70	0.80
Current Workload	0.9	0.70	0.80	0.90	0.90	0.70	0.65	0.80	0.85

The QFD model was applied to calculate API for each A/E using the owner's provided measures of A/E's PQC and desired OPR. Three different process matrices were developed for the A/Es. Figures 5 and 6 show the process matrices of consultant B and C, respectively. Table presents the PS and API of the evaluated A/Es. Accordingly, the QFD model suggested selecting consultant B, which achieved the highest API score (135.73). The owner concurred with the QFD model findings and admitted that selecting consultant C was wrong and agreed with the QFD model results, which showed that consultant B should have been hired for the project.

QFD model shows that consultant C has a better project context quality than consultant B (B's PHI = 16.11 and C's PHI = 9.17). However, consultant B outperforms consultant C in all capabilities. QFD model demonstrates the strengths of consultant B compared to consultant C's weaknesses. The prequalification score (PHI) for consultant B's design quality is almost twice of those for consultant C (B's PHI = 16.11 and C's PHI = 7.66). The design quality of consultant C was the worst compared to the other two A/Es. This deficiency alone resulted in severe project defects, which reduced the plant production capacity by 50% for one year due to improper load calculations. The owner took consultant C to the court requesting compensation for lost production and for repairing the plant.

The model shows that consultant B has much better staff quality than consultant C (B's PHI = 12.83 and DH's PHI = 7.13). Moreover, consultant B has better construction estimate capability than consultant C (B's PHI = 9.62 and DH's PHI = 7.21). The owner also stated that consultant C's construction estimation was insufficient, where the project estimate was about 37.5% more than the actual cost, which caused the construction contractor to request changes to all the unit rate prices due to differences in quantities.

		Prequalification Criteria (PQC)													
		Technical Experience	Design quality	Staff Quality	Past Performance	Key Designer	Design service Time	Construction estimation quality	Project Engagement	Bid Quality	Project Context	Number of years in business	Specialty designing services	Current Workload	
	PW	0.95	0.9	0.9	0.9	0.9	0.95	0.8	0.7	0.85	0.7	0.9	0.5	0.7	PSW
Project Requirements	0.8	6.02	5.10	4.86	4.64	4.21	4.71	3.70	3.43	4.19	3.12	2.83	1.48	2.04	50.34
	1	7.52	6.37	5.70	5.80	5.06	6.36	4.32	4.28	5.66	4.08	3.30	1.85	2.93	63.24
	0.4	2.56	2.31	2.28	2.06	1.89	2.39	1.61	1.46	1.56	1.42	1.07	0.63	0.93	22.15
	PSH	16.11	13.78	12.83	12.50	11.16	13.46	9.62	9.17	11.41	8.63	7.20	3.95	5.90	135.73

Figure 5: Process Matrix calculation for Consultant B.

		Prequalification Criteria (PQC)													
		Technical Experience	Design quality	Staff Quality	Past Performance	Key Designer	Design service Time	Construction estimation quality	Project Engagement	Bid Quality	Project Context	Number of years in business	Specialty designing services	Current Workload	
	PW	0.85	0.5	0.5	0.75	0.9	0.2	0.6	0.7	0.9	0.9	0.85	0.35	0.8	PSW
Project Requirements	0.8	5.39	2.83	2.70	3.87	4.21	0.99	2.77	3.43	4.44	4.03	2.67	1.03	2.33	40.69
	1	6.73	3.54	3.17	4.83	5.06	1.34	3.24	4.28	6.00	5.25	3.12	1.29	3.35	51.20
	0.4	2.30	1.28	1.27	1.71	1.89	0.50	1.20	1.46	1.65	1.82	1.01	0.44	1.06	17.60
	PSH	14.41	7.66	7.13	10.42	11.16	2.83	7.21	9.17	12.09	11.10	6.80	2.77	6.74	109.49

Figure 6: Process Matrix calculation for Consultant C.

Moreover, consultant B has much better design service time than consultant C (B's PHI = 13.46 and C's PHI = 2.83). The required design time was of an essence to the owner, but consultant C completed the design package way beyond the agreed-upon eight months design duration. Consultant C submitted partial drawings after two years to be constructed by the contractor instead of the whole package leading to a three-year delay for the whole project. The owner terminated the contract with consultant C and replaced it with consultant B to complete the project and do a proper design and correct the low design quality provided by consultant C. Both consultants have similar prequalification scores in project engagement and key designer. The owner agrees that they should have measured staff quality, design service time, and construction estimation time, which were not considered in their existing system.

Table 5: QFD Consultant Rankings for Owner 1's Project

Rank	Consultant	PS	CPI
2	Consultant A	110.61	0.6819
1	Consultant B	135.73	0.8368
3	Consultant C	109.49	0.6750
	Max PS	162.21	

QFD model validation with owner 2

Owner 2 is a semi-private organization located in Dammam, Saudi Arabia, employing between 250 and 500 employees and awards several construction contracts averaging in value more than SR100 million annually. The owner has a preprepared list of prequalified A/Es from which he selects and invites several A/Es based on predetermined criteria and uses the price-based system to select A/Es. The owner provided an infrastructure road and bridge for this study that are considered one of Dammam's main roads. The owner asserted that OPR as follows: time is extremely high important (PW=1), quality is highly important (PW=0.8), and the cost is a medium important (PW=0.6) where the project could be extended to an acceptable limit. The value of this project is more than SR100 million. Three A/Es designated KA, DH, and AM were selected from the owner's preprepared list and invited to submit their design fees. The owner awarded the design contract to consultant KA for more than SR4 million.

The QFD model was applied to calculate A/Es' APIs using the owner's provided measures of A/E's PQC and desired OPR. The QFD model produced the API and are shown in Table 6. QFD model suggested consultant DH for the project and placed KA at the bottom of the list. The owner agreed with QFD selection and asserted that consultant DH should have been selected as he would have been more appropriate for the project.

Table 6: Consultant Rankings for Owner 2's Project

	QFD Model		
Rank	**Consultant**	**PS**	**CPI**
1	DH	135.17	0.7706
2	KA	131.69	0.7507
3	AM	132.21	0.7537
	Max PS	175.42	

QFD model shows that most of KA's prequalification scores (PHI) are better or equal to those of DH's. However, DH outscored KA in design quality (KA's PHI = 6.64 and DH's PHI = 11.62), construction estimation quality (KA's PHI = 3.91 and DH's PHI = 10.42), and project engagement (KA's PHI = 7.07 and DH's PHI = 12.73). The owner concurred with the QFD model findings and indicated that they were supposed to have project engagement during the evaluation process, where consultant AK has a good designing quality. However, the project was the lowest priority to the consultant, causing him to subcontract the work to a low-quality designer. The owner explained that consultant KA did not give proper engagement to the project and subcontracted a good portion of the project to a small A/E. At the beginning of the construction stage, the owner discovered that the project could not be constructed due to low design quality mandated an intensive design review by a third party who indicated significant design errors that consultant KA agreed to redesigned. However, the new design manifested SR65 million over the allocated budget, causing a bitter dispute between the owner and consultant KA, where the owner claimed compensation for the cost increase. Moreover, the project time was an essential requirement, and the project was delayed by two years. The owner agreed that consultant DH should have been awarded the project, where the project engagement was a high priority. If consultant DH had been awarded the contract, he would have put all the effort into completing the project per the OPR.

QFD model validation with owner 3

Owner 3 is a semi-private utility services organization located in Jubail, Saudi Arabia, and employs more than 2500 employees. The owner uses the two envelopes to award the design contract. One envelop, designated technical, contains an A/Es predetermined PQC such as technical experience, design quality, staff quality, and bid quality. The second envelop, designated commercial contains the corresponding A/E's proposed design fee. The owner evaluates the technical envelope, and A/Es with evaluation scores of 70% are considered for the project. The owner awards the design contract to the A/E offering the lowest design fee regardless of his evaluation scores. The owner offered for the study an office building that cost more than SR100 million to build. The owner asserted that OPR as follows: cost is extremely high important (PW=1), quality is highly important (PW=0.8), and time is a medium important (PW=0.6) where the project could be extended to an acceptable limited not to exceed six months. Three A/Es designated E, F, and G passed the set qualification threshold. Consultant F who had the lowest qualification scores, was awarded the design contract for more than SR4 million.

The QFD model was applied to calculate API for each A/E using the owner's provided measures of A/E's PQC and desired OPR. The QFD model produced the APIs for the three A/Es, shown in Table 7. QFD model suggested consultant G for the project and placed consultant B at the bottom of the list. The owner concurred with QFD selection and asserted that consultant G should have been selected as he would have been more appropriate for the project.

Table 7: Consultant Rankings for Owner 3’s Project

	QFD Model		
Rank	**Consultant**	**PS**	**CPI**
1	Consultant E	132.91	0.7747
2	Consultant F	123.28	0.7185
3	Consultant G	144.64	0.8430
	Max PS	171.57	

QFD model reveals that consultant G's prequalification scores (PHI) are slightly better or equal to consultant F's. However, consultant G outscored consultant F in technical experience (G's PHI = 16.05 and DH's PHI = 13.38), project engagement (G's PHI = 11.08 and F's PHI = 8.27), project context (G's PHI = 10.43 and F's PHI = 8.48), and the number of years in business (G's PHI = 7.06 and F's PHI = 4.98).

The owner agreed that consultant F did not give proper priority to the project causing low project quality. Moreover, the project overruns the project budget by 15%, which is considered acceptable. Besides, the project schedule was 45% above the project required time. The owner believes that the project quality and time requirement could have been achieved, provided consultant G was assigned.

V. CONCLUSION

It was possible to develop an A/E selection model using the quality function deployment (QFD) method. The developed model considers both A/Es' prequalification criteria and project owners' requirements. The model effectively achieves the most competent A/Es for providing architectural and/or engineering services for industrial, engineering, and building projects with high reliability. The QFD model differs drastically from all various available models for A/Es prequalification, where the QFD model evaluates A/Es according to the project owners' requirements, and the existing models mostly focus on the A/Es selection criteria.

Owners are advised to use the developed QFD model to select A/Es for their projects. The model is based on qualification criteria and project constraints. The owners are also advised to refrain from awarding design contracts to A/Es based on project fees, representing a fraction of the project's total cost.

REFERENCES

[1] Haviland, D. (2000) You and your architect. American Institute of Architects, http://www.aiapvc.org/yourarch.htm.

[2] AIBC (1998) How to find, select and engage an architect. Architectural Institute of British Columbia, http://www.aibc.bc.ca/public/seeking_an_arch/selecting.html.

[3] CEC/PA (2000) Selecting the right consulting engineer. Consulting Engineers Council of Pennsylvania, http://www.cecpa.org/selecting_a_ce.htm.

[4] CEC/DE (2000) How to Select an Engineer. Consulting Engineers Council of Delaware, http://www.cecde.org/qbs.html.

[5] CIC (2014) A guide to quality-based selection of consultants (a key to design quality. London: Construction Industry Council.

[6] Assaf, S. and Al-Hejji S. (2005). Causes of Delay in Large Construction Projects. International Journal of Project Management, vol. 24, no. 4, 2006, pp. 349–357., doi:10.1016/j.ijproman.2005.11.010.

[7] Assaf, S., Hassanain, M., Hadidi, L., and Amman, A. (2017). A systematic approach for the selection of the architect/engineer professional in construction projects. Architecture, Civil Engineering, Environment, 10(4), 5–14. doi: 10.21307/acee-2017-047

[8] Shash, A. A. and Habash, S. I. (2020). Construction Contract Conversion: An Approach to Resolve Disputes.Journal of Engineering, Project, and Production Management, 10(3), 162-169. DOI: 10.2478/jeppm-2020-0018

[9] Babatunde, S., Opawole, A., Ujaddughe, I. (2012). An appraisal of project procurement methods in the Nigerian construction industry. Civil Engineering Dimension, 14(2). doi:10.9744/ced.12.1.1-7.

[10] Boer, L., Labro, E., and Morlacchi, P. (2001). A review of methods supporting supplier selection. European Journal of Purchasing and Supply Management, 7(2), 75–89. doi:10.1016/s0969-7012(00)00028-9.

[11] Elwardani, M., Messner, J., and Horman, M. (2006). Comparing procurement methods for design-build projects. Journal of Construction Engineering and Management, 132(3), 230–238. doi:10.1061/(asce)0733-9364(2006)132:3(230).

[12] Kasma, D. R. (1987). Consultant selection. Journal of Management in Engineering, 3(4), 288–296. doi: 10.1061/(ASCE)9742-597x (1987)3:4(288)

[13] Sporrong, J. (2011). Criteria in Consultant Selection: Public Procurement of Architectural and Engineering Services.” Construction Economics and Building, vol. 11, no. 4, pp. 59–76., doi:10.5130/ajceb.v11i4.2297.

[14] Christodoulou, S., Griffis, F., Barrett, L., and Okungbowa, M. (2004). Qualifications-based selection of professional A/E services. Journal of Management in Engineering, 20(2), 34–41. doi:10.1061/(asce)0742-597x(2004)20:2(34).

[15] Ng, S., Kumaraswamy, M. and Chow, L (2001) Selecting consultants through combined technical and fee assessment: a Hong Kong study. In: Akintoye, A (Ed.), 17th Annual ARCOM Conference, 5-7 September

2001, University of Salford. Association of Researchers in Construction Management, Vol. 1, 639-47

[16] Gronroos, C. (1984) Strategic management and marketing in the service sector. Helsinki: Swedish School of Economics and Business Administration.

[17] Latham, M. (1994) Constructing the Team, HMSO, London.

[18] Day, W. (1998) Performance over price. American School & University, http://www.asumag.com/magazine/Archives/0898profsvcs.html.

[19] Peck, M. (1998) NSW Two Envelope System not the solution. Royal Australian Institute of Architects, http://www.raia.com.au/media/html/pr23jan98.htm.

[20] Chinowsky, P., and Kingsley, G. A. (2009). An analysis of issues pertaining to qualifications-based selection. Washington, DC: ACEC.

[21] Shelton, B. (2018). Qualifications-Based Selection (QBS): Best Practice for Architecture, Engineering and Construction Management/General Contractor Procurement in Canada. A QBS Canada Publication. www.QBSCanada.ca

[22] Molenaar, K. R., & Gransberg, D. D. (2001). Design-builder selection for small highway projects. Journal of Management in Engineering, 17(4), 214–223. doi:10.1061/(asce)0742-597x(2001)17:4(214).

[23] Potter, K. J. and Sanvido, V. (1995). Implementing a design/build prequalification systems; Journal of Management in Engineering 11(3), 30–34.

[24] Cheung, F., Kuen, J., and Skitmore, R. (2002) Multicriteria Evaluation Model for Selection of Architectural Consultants. Construction Management and Economics. Vol. 20 (7), pp. 569-580.

[25] Al-Besher, M. F. (1998). A conceptual model for consultant selection in Saudi Arabia. Mater Thesis, King Fahd University of Petroleum & Minerals, Saudi Arabia.

[26] Martinovic, N., and Delibasic, B. (2014). Selection of the best consultant for SAP ERP project using combined AHP-IBA approach. Yugoslav Journal of Operations Research YUJOR, 24(3), 383–398. doi: 10.2298/yjor140228036m

[27] Ling, Y. Y. (2002). Model for predicting performance of architects and engineers; Journal of Construction Engineering and Management 128(5), 446–455.

[28] Ling, Y. (2003). A conceptual model for selection of architects by project managers in Singapore. International Journal of Project Management, 21(2), 135–144., doi:10.1016/s0263-7863(02)00014-5.

[29] Ng, S. T., and Chow, L. K. (2004). Evaluating engineering consultants' general capabilities during the pre‐selection process – a Hong Kong study. Engineering, Construction and Architectural Management, 11(3), 150–158. doi: 10.1108/09699980410535769

[30] Chow, L., and Ng, S. (2007). A fuzzy gap analysis model for evaluating the performance of engineering consultants. Automation in Construction, 16(4), 425–435. doi:10.1016/j.autcon.2006.07.010.

[31] Bowen, P. A. (1999). Client briefing processes and procurement method selection: a South African study. Engineering Construction and Architectural Management, 6(2), 91. doi:10.1046/j.1365-232x.1999.00075.x.

[32] Ghiya, K.K., Bahill, A.T., Chapman, W.L. (1999), QFD: Validating Robustness, Quality Engineering, Vol. 11, Issue 4, p. 593-611.

[33] Cohen, L. (1995) Quality Function Deployment: How to Make QFD Work for You, Addison-Wesley, Reading, MA.

[34] Ahmed, S.M., Sang, L.P. and Torbica, Z.M. (2003) Use of quality function deployment in civil engineering capital project planning. Journal of Construction Engineering and Management, 129(4), 358–68.

[35] Delgado-Hernandez, D., Bampton, K., and Aspinwall, E. (2007).Quality function deployment in construction. Construction Management and Economics. Vol. 25, 597–609

[36] Chan, L.-K., & Wu, M.-L. (2002). Quality function deployment: A comprehensive review of its concepts and methods. Quality Engineering, 15(1), 23–35. doi: 10.1081/qen-120006708

[37] Pheng, L.S. and Yeap, L. (2001) Quality function deployment in design/build projects. Journal of Architectural Engineering, 7(2), 30–9.

[38] Oswald, T. H., and Burati, J. L., Jr. (1993). Adaptation of quality function deployment to engineering and construction project development. Rep. to Construction Industry Institute, Clemson University, Clemson, S.C.

[39] Mallon, J.C. and Mulligan, D.E. (1993) Quality function deployment: a system for meeting customers' needs. Journal of Construction Engineering and Management, 119(3), 516–31.

[40] Eldin, N. and Hikle, V. (2003) Pilot study of quality function deployment in construction projects. Journal of Construction Engineering and Management, 129(3), 314–29.

[41] Arditi, D. and Lee, D. (2003) Assessing the corporate service quality performance of design-build contractors using quality function deployment. Construction Management and Economics, 21(2), 175–85.

[42] Lee, D. and Arditi, D. (2006) Total quality performance of design/build firms using quality function deployment. Journal of Construction Engineering and Management, 132 (1), 49–57.

[43] Cariaga, I., El-Diraby, T. and Osman, H. (2007) Integrating value analysis and quality function deployment for evaluating design alternatives. Journal of Construction Engineering and Management, 133(10), 761–70.

[44] Abdul-Rahman, H., Kwan, C.L. and Woods, P.C. (1999). Quality function deployment in construction design: application in low-cost housing design. International Journal of Quality & Reliability Management, 16(6), 591–605.

[45] Ignatius, J., Rahman, A. Yazdani, M., Saparauskas, J., and Haron, S. (2016). An Integrated Fuzzy ANP-QFD Approach for Green Building Assessment. Journal of Civil Engineering and Management, 2016 Volume 22(4): 551–563.

[46] Kamara, J.M., Anumba, C.J. and Evbuomwan, N.F.O. (2000) Establishing and processing client requirements: a key aspect of concurrent engineering in construction. Engineering, Construction and Architectural Management, 7 (1), 15–28.

[47] Yang, Y.Q., Wang, S.Q., Dulaimi, M. and Low, S.P. (2003) A fuzzy quality function deployment system for buildable design decision-makings. Automation in Construction, 12(4), 381–93.

[48] Dikmen, I., Talat, M. and Kiziltas, S. (2005) Strategic use of quality function deployment in the construction industry. Building and Environment, 40(2), 245–55.

[49] Jafari, A. (2013). A contractor pre-qualification model based on the quality function deployment method. Construction Management and Economics, Vol. 31, No. 7, 746–760,

[50] Wee, T., Aurisicchio, M., and Starzyk, I. (2017). The Application of Quality Functional Deployment to Modular Offsite Construction Products. 21st International Conference on Engineering Design, ICED17 21-25 August, The University of British Colombia, Vancouver, Canada

[51] Juan, Y.K., Perng, Y.H., Castro-Lacouture, D. and Lu, K. S. (2009) Housing refurbishment contractors selection based on a hybrid fuzzy-QFD approach. Automation in Construction, 18, 139–44.

[52] Yasamis-Speroni, F., Lee, D. and Arditi, D. (2012) Evaluating the quality performance of pavement contractors. Journal of Construction Engineering and Management, 138(10), 1114–24.

[53] Westerveld, E. (2003) The project excellence model: linking success criteria and critical success factors. International Journal of Project Management, 21(6), 411–8.

[54] Wang, X. and Huang, J. (2006) The relationships between key stakeholders' project performance and project success: perceptions of Chinese construction supervising engineers. International Journal of Project Management, 24 (3), 253–60.

[55] Tabish, S.Z.S. and Jha, K.N. (2012) Success traits for a construction project. Journal of Construction Engineering and Management, 138(10), 1131–8.

[56] Alzahrani, J.I. and Emsley, M.W. (2013) The impact of contractors' attributes on construction project success: a post construction evaluation. International Journal of Project Management, 31(2), 313–22.

[57] Toh, T., Ting, C., Ali, K., Aliagha, G., and Munir, O. (2012). Critical Cost Factors of Building Construction Projects in Malaysia. Procedia - Social and Behavioral Sciences, 57, 360-367. doi:10.1016/j.sbspro.2012.09.1198

[58] Shash, A. and Ajairi, F. (2021). Impact of Owners' Project Requirements on A/E Prequalification Criteria (POQ). International Journal of Advanced Engineering and Management, Vol. 6, No. 1, pp 54-69.

[59] American Council of Engineering Companies (ACEC) of Oklahoma. (no date). How to Select a Consulting Engineer for Your Project, American Council of Engineering Companies of Oklahoma, 220 N.E. 28th Street, Suite 135 Oklahoma City, OK 73105, Web Site: www.acecok.org

[60] Department of Treasury and Finance (DTF). (2019). Procurement Practices Manual: Best Practice for Engagement of Consultants (CIVIC AND CIVIL). Tasmanian Government. ISBN 978-0-7246-5489-5.

[61] Akao, Y. (Ed.). (1990). Quality function deployment: Integrating customer requirements into product design. Productivity Press.

[62] Chan, L.-K., & Wu, M.-L. (2002). Quality function deployment: a literature review." European Journal of Operational Research, 143(3), 463–497. doi:10.1016/s0377-2217(02)00178-9

[63] Hauser, J., Griffin, A., Gaskin, S., and Klein, R. (2010). Quality Function Deployment (QFD). In book: Wiley International Encyclopedia of Marketing. DOI: 10.1002/9781444316568.wiem05023

[64] Ola, A. and Michael, A. (2017). Impact of Contractors' Prequalification Criteria on Civil Engineering Project Quality Performance. International Journal of Advanced Engineering, Management and Science (IJAEMS) [Vol-3, Issue-9, pp 941-947.

[65] Sawyer, J. (2014). Qualifications Based Selection of Construction Services: Evaluation Criteria that Best Differentiate Contractor Qualifications. A Thesis Presented in Partial Fulfillment of the Requirements for the Degree Master of Science, Arizona State University.

[66] Silva, G., Warnakulasuriya, B., and Arachchige, B. (2016). Criteria for Construction Project Success: A Literature Review. 13th International Conference on Business Management.