Total Quality Performance of Design/Build Firms Using Quality Function Deployment

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Abstract: The belief that the design–build (D/B) project delivery system does not lend itself to effective quality assurance and control is quite common in construction circles. Total quality consists of: (1) the corporate quality culture; (2) the quality of the project service; and (3) the quality of the constructed facility. This paper describes a model that was developed to measure the total quality of a D/B firm using quality function deployment (QFD). The first part of this model is described elsewhere and measures the effectiveness of the corporate quality culture and the quality of the service when delivering a project by using QFD. The second part of the model is described in this paper. It makes use of eight building quality factors, three building performance factors, and the relationships between building quality and performance factors (obtained from building users/evaluators) and it measures the quality performance of the constructed facility by using QFD. A total quality performance index is generated by combining the quality performance at the corporate, project, and product levels. The total quality performance measurement model described in this paper can be used by D/B firms to benchmark themselves against their competitors or to monitor their own performance. It can also be used by owners to rank D/B firms relative to their total quality performance.

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Introduction

It is not possible to precisely measure the quality performance of the construction industry in general because every project is unique. Quality performance depends on the segment [general contracting, design/build (D/B), design, etc.] of the industry where the firm is active. This research is limited to only one segment of the construction industry, namely the D/B sector.

To clearly define the research domain, D/B is defined as the owner-driven project delivery system in which one integrated entity forges a single contract with the owner. The single entity assumes single source risk and responsibility (DBIA, 1998). The D/B firms handle all phases of a project from planning, conceptual and preliminary design, detailed design, and procurement through construction to operation with sole responsibility within their organization. Responsibilities are delegated to diverse functions such as contract, design, procurement, construction, and servicing as the conceptual design shifts to detailed design and construction to final product.

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Many D/B professionals insist that the advantages of the D/B method outweigh by far its disadvantages. The advantages and disadvantages to project participants are well documented in the literature (Yates 1995; DBIA 1998). The D/B system is more efficient, minimizes the possibility of claims and changes, establishes budget integrity, develops a strong working relationship among parties, integrates value engineering into the design process much sooner than in traditional methods, conceptualizes the completed project accurately at an early stage, and saves construction overhead costs and project-financing costs by reducing project delivery time. The fact that the D/B method carries a single source of responsibility helps in achieving these advantages. But these advantages are valuable only when the D/B project is performed in acceptable quality. The construction owner does not retain the authority of the checks and balances in a D/B project since the owner does not have the capability to let a designer administer the quality performance of a contractor. That is why the management of quality is an important issue in the delivery of D/B projects, requiring a more elaborate measurement tool of quality performance than any other project delivery system.

If a project can be defined as a temporary endeavor undertaken to create a unique product (PMI 2000), the project that is delivered by a D/B firm can be considered to be a unique entity consisting of product (e.g., building, cement plant, etc.) and service (at corporate and project levels). The construction quality assurance system is a scoring system developed by the Construction Industry Development Board in Singapore that focuses on measuring the quality of the workmanship provided by building contractors (Pheng and Willie 1996). The *PASS* system (Liu 2003), which has been used by the Housing Department of Hong Kong, analyzes lists of defects in completed buildings and monitors the quality of workmanship and of some managerial activities

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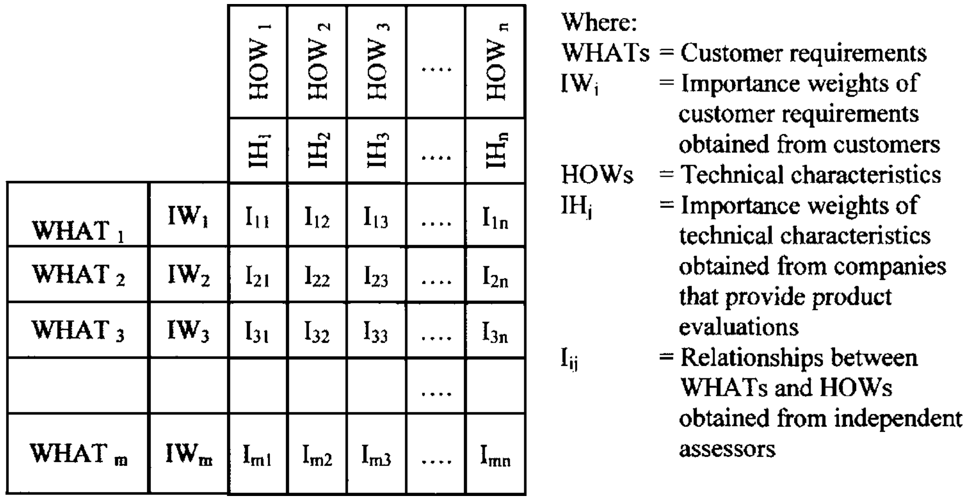

Fig. 1. Data matrix

(e.g., cleanliness and maintenance). None of these systems comprehensively deal with total quality at: (1) the product (i.e., constructed facility); (2) corporate; and (3) project levels.

Previous research focused on measuring the service quality performance of D/B firms at the corporate (Arditi and Lee 2003) and project (Arditi and Lee 2004) levels, whereas this research focuses on measuring the quality performance at the product level. The outcome of these three studies is a tool that measures the total quality performance of D/B firms including product quality of the constructed facility and service quality at the corporate and project levels.

The measurement tool combines experience captured from three expert pools that consist of construction owners, senior managers in D/B firms, a quality system assessor who has extensive experience with D/B firms and projects, and building users/evaluators. The measurement is conducted by performing quality function deployment (QFD) on data that reflect: (1) the needs and expectations of construction owners relative to service quality factors and quality management system components at the corporate and project levels; (2) the strength of the relationship between service quality factors and quality management system components at the corporate and project levels; (3) the needs and expectations of building users/evaluators relative to building performance factors and building quality factors; (4) the strength of the relationship between building performance factors and building quality factors; and (5) the pursued and implemented quality management system in place in D/B projects.

Quality Function Deployment

The QFD is defined as "a technique to deploy customer requirements into design characteristics and deploy them into subsystems, components, materials, and production processes" (Hoyle 1998). The elements of the QFD "House of Quality" are presented in Figs. 1 and 2. The process of QFD involves five steps (Akao 1990; Akao and Mizuno 1994; Shillito 1994; Zairi and Youssef 1995).

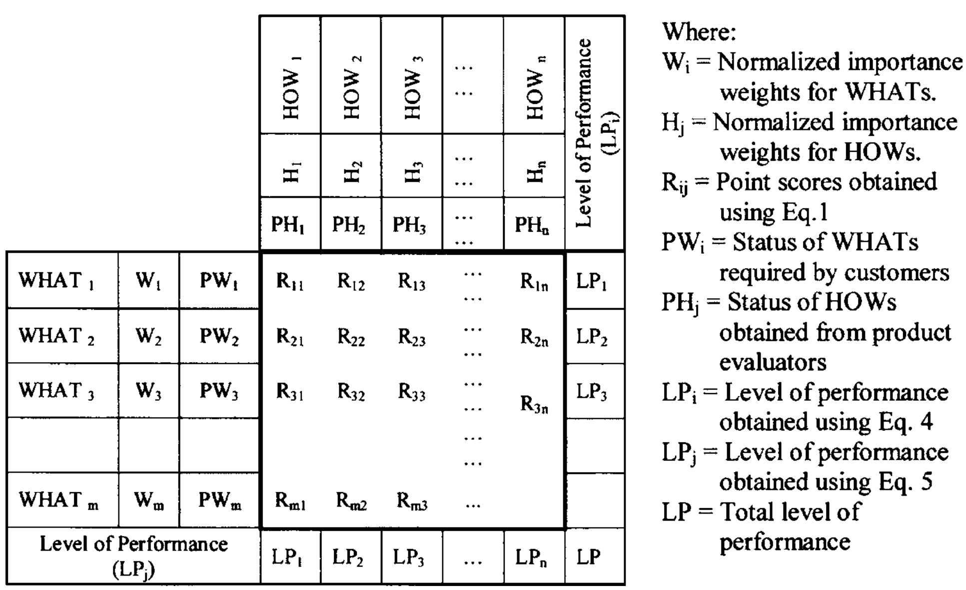

Fig. 2. Process matrix

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1. Identifying the elements and collecting the data—Fig. 1 shows the data matrix that contains information (IW_i) about customer requirements (the WHATs), the technical characteristics (IHj) of the companies providing the product (the HOWs), and the strength of their interrelationships (I_{ij}).
2. Processing of the data in the data matrix—The information in the highlighted column ④ and row ⑤ of the process matrix in Fig. 2 represents the existing status (PW_i and PH_j) of the WHATs and HOWs in a product. They are specified on a scale of 1–5, where 1 is "poor" and 5 "excellent."

The boxed-in point scores (R_{ij}) for each intersection between WHATs and HOWs are calculated by multiplying the mean of the relative importance of a HOW and that of a WHAT by the strength of its relationships (I_{ij}) specified in Fig. 1

$$R_{ij} = \frac{(W_i \times PW_i) + (H_j \times PH_j)}{2} \times I_{ij} \tag{1}$$

where R_{ij}=point scores for each intersection between WHATs and HOWs; PW_i=status of each WHAT; PH_j=status of each HOW; W_i=normalized weight of importance of each WHAT; H_j=normalized weight of importance of each HOW; and I_{ij}=strength of the relationships between WHATs and HOWs (from Fig. 1).

The importance ratings in the data matrix in Fig. 1 are normalized and also add up to 1 in the process matrix in Fig. 2

$$\sum_{i=1}^{m} W_i = 1 \tag{2}$$

$$\sum_{j=1}^{n} H_j = 1 \tag{3}$$

3. Calculating the maximum achievable level of performance—The maximum level of performance (max LP) is achieved if the existing status in all WHATs (PW_i) and in all HOWs (PH_j) are rated as 5 (excellent).

The maximum level of performance (Max LP_i) for each WHAT_i is calculated using the following equation. These values are placed in the right most column of the process matrix in Fig. 2

$$\text{Max LP}_i = \sum_{j=1}^{n} R_{ij} \quad \text{for } 1 \leqslant i \leqslant m \tag{4}$$

The maximum level of performance (Max LP_j) for each HOW_j is calculated using Eq. (5). These values are placed in the bottom row of the process matrix in Fig. 2

$$\text{Max LP}_j = \sum_{i=1}^{m} R_{ij} \quad (1 \leqslant j \leqslant n) \tag{5}$$

The maximum level of performance (Max LP) for a D/B firm is given by the relationship in the following equation. This value is located in the bottom right corner cell of the process matrix in Fig. 2

$$\text{Max LP} = \sum_{i=1}^{m} \text{Max LP}_i = \sum_{j=1}^{n} \text{Max LP}_j \tag{6}$$

Max LP constitutes the maximum achievable performance for the firm.

4. Calculating the actual level of performance—It is likely that the actual levels of performance in WHATs and HOWs will take values between 1 and 5. The actual level of performance (Actual LP) is calculated by using the same process used in 3. The only difference is that the status of the WHATs (PW_i) and the HOWs (PH_j) are rated individually for the case at hand (i.e., not all receive a maximum value of 5 as in Step 3).
5. Calculating quality performance—The quality performance index (QPI) can be obtained from the following equation:

$$\text{QPI} = \frac{\text{actual } LP \text{ (from step 4)}}{\text{Max } LP \text{ (from step 3)}} \times 100\% \tag{7}$$

Measuring Total Quality Performance

The construction industry is characterized not only as a service industry sharing certain characteristics with manufacturing industries but also as a "project-based" industry (Woodward and Benes 1980; PMI 2000). In addition to high service quality at the corporate and project levels, the owner also demands high quality in the constructed facility. The owner will come closest to its desired quality by selecting a D/B firm based on the totality of the firm's quality performance including the quality of its corporate service, project service and constructed facility. The interests of the D/B firm should be aligned with the construction owner's "total quality" objectives.

The total quality performance measurement model uses QFD and is shown in Fig. 3. The details related to the left part of the model that correspond to the measurement of service quality performance at the corporate and project levels are described by Arditi and Lee (2003) and Arditi and Lee (2004), respectively.

The factors used for measuring quality should be directly related to customers' needs and expectations and should be easily quantifiable. For example, Parasuraman et al.'s (1985) conceptual model for measuring service quality made use of ten dimensions transcending different types of services that customers use in forming expectations about and perceptions of services received. A discussion of Parasumaran et al.'s model, including later refinements and critiques, can be found in Arditi and Lee (2003). The ten service quality factors used in the study of service quality in D/B projects were adapted from the original ten dimensions identified by Parasuraman et al. (1985) and are presented in Table 1.

The performance level of the quality management system with respect to service quality is measured by means of quality management system components. The quality management system components at the corporate level that were used in the Arditi and Lee (2003) study were adapted from the criteria used by the Malcolm Baldrige National Quality Awards (Desatnick 1992) because the Malcolm Baldrige National Quality Award is one of the most widely accepted models of performance excellence (Black and Porter 1996; Wilson and Collier 2000; Curkovic et al. 2000). The six components along with their brief descriptions are presented in Table 2.

The quality management system components at project level that were used in the Arditi and Lee (2004) study were extracted from criteria used in PMI standards and include quality planning, quality assurance, and quality control (PMI 2000). Although these processes interact and at times overlap with each other, they consist of and include all activities required to ensure that the project will satisfy the quality requirements (Arditi and Lee 2004). A list

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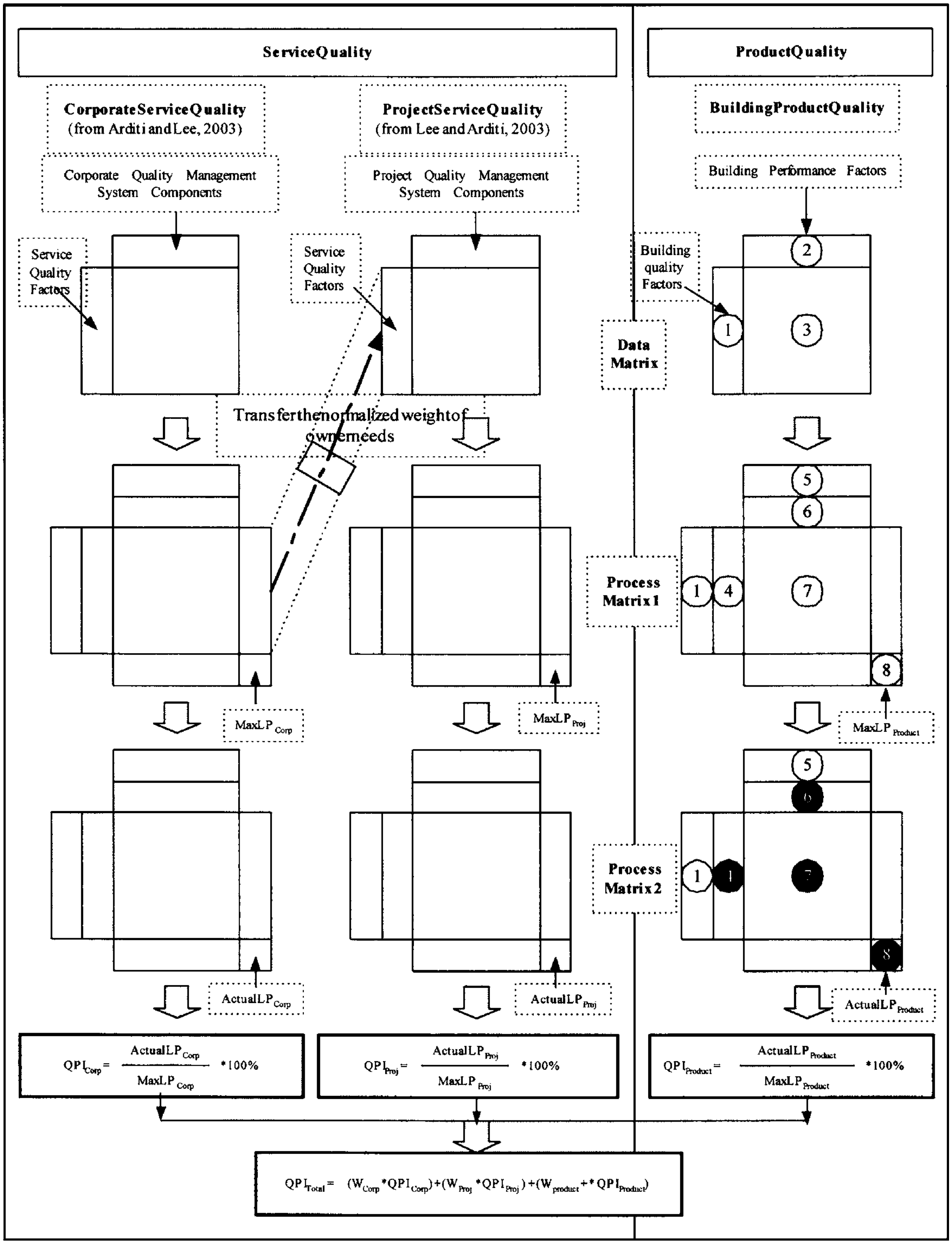

Fig. 3. Building product quality performance measurement model

of the project quality management system components and their definitions are presented in Table 3.

The details of the attributes and the data processing for the right part of the model presented in Fig. 3 that correspond to the measurement of the building product quality are as follows:

1. First column: This column includes eight "product quality factors" which were adapted from the eight dimensions identified as Garvin's (1988) product quality dimensions. These factors represent building users' quality requirements. Their brief descriptions are presented in Table 4. The relative importance rates of building product quality factors were reported by building users in a questionnaire survey on a scale of 1–10, where 1 represents "not important" and 10 "extremely important." The normalized weights of these product quality factors were calculated and inserted in the first column.
2. Row 2: This row includes three "building performance factors" which were adapted from the postoccupancy evaluation criteria developed by Preiser et al. (1988). They represent the technical characteristics with which constructed facilities are

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Table 1. Service Quality Factors (Modified from Parasuraman et al.'s 1985 Service Quality dimensions)

Service quality factors	Definitions
Minimum project duration	The duration of the contract itself, including the time for mobilization and demobilization on site.
Timeliness	The variation in the completion time of the contract compared to the scheduled date, including milestones.
Completeness	The number and value of the items on the punch list upon completion of the contract.
Courtesy	The degree of respect, politeness, consideration, and kindness of the design/build firm's site and office personnel.
Consistency and dependability	The extent to which the design/build firm provides the same level of service performance to all clients at different times.
Accessibility and convenience	The ease with which the contracting service is obtained from the design/build firm and approachability of the design/build firm for any problem.
Accuracy	The ability to provide the right service at the first time with minimum amount of rework and the extent to which the service complies with owner's requirements.
Responsiveness	The ability to react to the problems encountered during the project, the ability to withstand the variation of requirements during the project, and focus on meeting the client's goals.
Communication	The ability to disseminate information about the process of the project and to listen to the owner.
Understanding the customer	The ability that the design/build firm makes to understand the specific needs of each owner.

expected to meet building users' needs and expectations. Their brief descriptions are presented in Table 5. The relative importance of building performance factors was reported by building users/evaluators in a questionnaire survey on a scale of 1–10, where 1 represents "not important" and 10 "extremely important."

3. Matrix 3: This matrix represents the strength of the relationships between building users' needs and expectations with respect to building product quality factors (first column) and the building performance factors in place at the constructed facility (row 2). This information was obtained from building users/evaluators by means of a survey instrument on a scale of 0–5 where 0 represents "no relationship" and 5 "perfect (one-on-one) relationship."
4. Fourth column: This column represents the status of building product quality factors under perfect conditions (i.e., they all score a maximum 5).
5. Row 5: This row features normalized importance weights for building performance factors such that the condition set in Eq. (3) is satisfied.
6. Row 6: This row represents the status of building performance factors under perfect conditions (i.e., they all score a maximum 5).
7. Matrix 7: The point scores (R_{ij}) were calculated by the synthesis of the information in attributes 1, 3, 4, 5, and 6 according to Eq. (1).
8. Cell 8: The maximum level of building product quality performance at the product level under perfect conditions is calculated using the procedure defined in Eqs. (4)–(6).
9. Fourth Column: This column represents the status of building product quality factors under actual conditions in a particular constructed facility, as assigned by building users.
10. Row 6: This row represents the status of building performance factors under actual conditions in a particular constructed facility, as reported by building users/evaluators.
11. Matrix 7: The point scores (R_{ij}) were calculated by the synthesis of the information in attributes 1, 3, 5, 4, and 6 according to Eq. (1).
12. Cell 8: The actual level of building product quality performance under actual conditions is calculated using the procedure defined in Eqs. (4)–(6).

Design of Survey Questionnaires

The participants who have an impact on service quality performance in D/B construction are identified based on their roles, responsibilities, needs, and expectations as: (1) construction owners, (2) senior executives of D/B firms, (3) quality system assessors and/or consultants, and (4) building residents/evaluators. Four sets of questionnaires were therefore prepared and administered to these four populations.

1. A survey questionnaire was administered to all 127 construc-

Table 2. Corporate Quality Management System Components (Modified from Malcolm Baldrige National Quality Awards Criteria)

Corporate quality management system components	Definitions
Leadership	The degree of encouragement by top management so as to lead to quality performance throughout the organization, the delegation of quality responsibility and authority to all levels of the design/build organization.
Client focus	The degree of importance that a firm places on client relationships and client satisfaction and the degree of knowledge about customers and the market.
Information and analysis	Collection, maintenance, and use of information and/or data for measuring and improving quality performance. Analysis and review of company performance by analyzing data collected within the organization, collection and use of comparative information to improve process of construction and the management of the organization.
Human resources development and management	Identification of the needs of employee education, training, and development to achieve the organization's success by incrementing the knowledge, skill, creativity, and motivation of its workforce.
Process management	Management of product and service processes, management of support processes, and management of supplier and partnering process.
Business results	Identification and evaluation of customer satisfaction results, financial and market results, human resource results, supplier and partner results, and company specific results.

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Table 3. Project Quality Management System Components (Modified from Project Management Institute Standards)

Project quality management system components	Definitions
Quality planning	Identifying which quality standards are relevant to the project and determining how to satisfy them.
Quality assurance	Evaluating overall project performance on a regular basis to provide confidence that the project will satisfy the relevant quality standards.
Quality control	Monitoring specific project results to determine if they comply with relevant quality standards and identifying ways to eliminate the causes of unsatisfactory performance.

tion owners of D/B construction listed in the database of the Design Build Institute of America (DBIA). The rate of response was 15.45%. The questionnaire sought information about the demographics of the respondents (e.g., company type, years of experience in the industry, job title, and project type) as well as the relative importance of service quality factors defined in Table 1. The details concerning this survey and the QFD process conducted using the collected data are described by Arditi and Lee (2003).

2. A survey questionnaire was administered to all 126 senior executives of the D/B firms listed in the database of DBIA. The rate of response was 17.36%. The questionnaire sought information about the senior executives in D/B firms who responded to the survey (i.e., company type, company specialty, years of experience in the industry, and title of the respondents) as well as the relative importance of quality management system components in place at the corporate level as defined in Table 2 and at the project level as defined in Table 3. The details concerning this survey and the QFD process conducted using the collected data at the corporate and project levels are described by Arditi and Lee (2003) and Arditi and Lee (2004), respectively.
3. A questionnaire was administered to a quality management system assessor who had experience with D/B construction. This type of respondent is hard to come by as quality assessment of D/B firms is a rare occurrence. This person was the representative of one of the largest quality consulting and training organizations in North America. This company has been in existence since 1983 and has operated nationally and internationally with several permanent offices in North America and six other countries. Its client base includes a large variety of companies in various industries, including D/B firms. The person who answered the questionnaire was fully familiar with D/B projects. The information obtained included the strength of the relationships between corporate quality management system components (i.e., the configuration of the corporate quality management system pursued by senior executives in D/B firms) and service quality factors (i.e., factors that owners use to set their quality needs and expectations) (Arditi and Lee 2003). It also included the strength of the relationships between project quality management system components and service quality factors (Arditi and Lee 2004).
4. A survey questionnaire was administered to 50 building users who were college students majoring in architecture. The rate of response was 76%: (1) the questionnaire sought information about the demographics of building users (i.e., the number of years they have resided in the building in question, the type of facility, and the number of years of residence in the United States) as well as the relative importance of building quality factors. This information reflects the needs and expectations of the building users. The building quality factors were extracted from Garvin's (1988) product quality dimensions. The definitions of building quality factors are presented in Table 4. (2) A survey questionnaire was administered to the same 50 building users who were college students majoring in architecture. In this survey, these 50 respondents doubled up as building evaluators because they are expected to have a good understanding of the issues due to their domain knowledge. The rate of response was 76%. In addition to the demographics information mentioned in the preceding bullet point, the respondents provided the relative importance of building performance factors (Table 5) in place in the buildings studied. The weights were used in the model after normalization. (3) The strength of the relationships between building quality factors and building perfor-

Table 4. Building Quality Factors (Modified from Garvin's 1988 Product Quality Dimensions and ISO 8402 Definitions)

Building quality factors	Definition
Performance	The measure to which the primary operating characteristics and functions of the building components meets the building users' basic functional and technical needs.
Usability	The degree of fulfillment of an intended usage requirement or reasonable expectations.
Dependability	The degree of confidence with which the building users may use the building to the end of its final life without failure, including reliability, maintainability, and maintenance-support performance.
Conformance	The degree to which the building product and its individual components fulfill the design standards, specifications, and regulations specifying requirements which include the stated and/or implied needs of user and the requirement of society that is resulted from laws, regulations, rules, codes, statues, and other consideration.
Safety	The degree to which the risk of harm or damage to building users is limited to an acceptable and/or perceivable level.
Economics	Adequate total construction cost, minimal maintenance cost, and expediting cost in parallel with the durability that is the expected operational life of use building users get from the building before replacement is preferred.
Aesthetics	The level of satisfaction the building users experience with the appearance and feel that the building provides even though it is obviously a dimension of quality for which there is a large number of individual judgments.
Perceived quality	The level of satisfaction the building user experiences with the building's image, including a perceived value, and previous performance of the Building contractor's other building products.

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Table 5. Building Performance Factors (Adapted from Preiser et al.'s 1988 Post-Occupancy Evaluation Research)

Building performance factors	Definitions
Technical elements	Fire safety, structural properties, ventilation systems, electrical systems, exterior walls, the roofs, interior finishes, acoustics, illumination, and environmental control systems.
Functional elements	The work-environment-related human factors concerning the dimensions and configuration of the designed environment, including the appropriate size, location, and distribution of storage, the effectiveness of the communication and workflow, the flexibility, potential for change, and building utilization and specialization.
Behavioral elements	The interpersonal distances maintained among individuals for the purpose of communication (territoriality), the control of access to an individual's or group's territory (privacy and interaction), the appropriateness of the needs of different occupant groups of a defined range of performance attributes (environmental perception), the meaning attached to the building's design (image and meaning), and the environmental cognition and orientation that create mental maps in the minds of a building's occupants.

mance factors were reported by the same respondents wearing their building evaluator hats. This information reflects the relationship between building users' expectations of building quality factors and the configuration of building performance factors.

The relative importance of: (1) corporate service quality, (2) project service quality, and (3) building product quality were prioritized by construction owners, senior managers in D/B firms, and the quality management system assessor. The score ranged from 1 to 10, where 1 is "not important" and 10 "very important."

Findings

The data collected through the first three surveys administered to D/B project owners, senior executives of D/B firms, and the quality management system assessor with experience in D/B projects are converted into Process Matrices 1 and 2 (Fig. 3) by using the QFD process. The details of this process are presented by Arditi and Lee (2003, 2004).

The data collected through the fourth survey administered to building users/evaluators are presented in Fig. 4. This data matrix corresponds to the matrix described in Step 1 in the Methodology section, i.e., the data matrix in Fig. 1 and the top matrix in Fig. 3. The information in column 1, row 2, and matrix 3 was obtained from building users/evaluators. Assuming that the maximum achievable performance status in each and every factor is a perfect 5, it is possible to perform the calculations described in Steps 2 and 3. Hence, Process Matrix 1 presented in Fig. 5 corresponds to the middle matrix in Fig. 3. Given the data collected in the surveys described earlier, the maximum level of performance expected in the constructed facilities is 17.454 (bottom right corner cell in Fig. 5).

As an example, let us now assume that a construction owner who commissions a building wants to assess the building's quality. If the building evaluators hired by the owner rate the status of the building performance factors in place in the constructed facility in use (recorded in the status row of Fig. 6) and the building users rate the building quality performance of the building in use, it is possible to make the calculations described in Steps 1–4 and produce Process Matrix 2 presented in Fig. 6; this matrix corresponds to the bottom matrix in Fig. 3. Given the status information for the particular constructed facility in the example, the actual level of performance expected in the case of the constructed facility in question is calculated as 13.536 (bottom right corner cell in Fig. 6). According to Eq. (7), which corresponds to the last step in Fig. 3, the QPI of the building in this example is obtained

		Building Performance Factors		
		Technical	Functional	Behavioral
Building Quality Factors	Normalized Importance Weights	0.375	0.279	0.346
Performance	0.125	**0.778**	**0.744**	**0.606**
Usability	0.127	**0.711**	**0.761**	**0.644**
Dependability	0.134	**0.694**	**0.656**	**0.500**
Conformance	0.108	**0.689**	**0.567**	**0.461**
Safety	0.137	**0.728**	**0.694**	**0.657**
Economic	0.123	**0.689**	**0.556**	**0.428**
Aesthetics	0.125	**0.633**	**0.556**	**0.650**
Perceived quality	0.121	**0.667**	**0.650**	**0.578**

Fig. 4. Data matrix

			Building Performance Factors			Maximum Level of Performance (Max LP_i)
			Technical	Functional	Technical	
Building Quality Factors	Normalized Importance Weights		0.375	0.279	0.346	
		Max Status	5	5	5	
Performance	0.125	5	**0.973**	**0.752**	**0.714**	2.439
Usability	0.127	5	**0.893**	**0.772**	**0.763**	2.428
Dependability	0.134	5	**0.883**	**0.676**	**0.600**	2.159
Conformance	0.108	5	**0.832**	**0.548**	**0.523**	1.903
Safety	0.137	5	**0.932**	**0.722**	**0.685**	2.339
Economic	0.123	5	**0.857**	**0.557**	**0.501**	1.915
Aesthetics	0.125	5	**0.792**	**0.561**	**0.766**	2.119
Perceived quality	0.121	5	**0.827**	**0.650**	**0.675**	2.152
Maximum Level of Performance (Max LP_j)			6.989	5.238	5.227	17.454

Fig. 5. Process matrix 1—maximum achievable level of performance

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Building Quality Factors	Normalized Importance Weights	Max Status	Building Performance Factors: Technical	Functional	Technical	Actual Level of Performance (Actual LP_i)
			0.375	0.279	0.346	
			3	5	4	
Performance	0.125	3	**0.584**	**0.659**	**0.533**	1.776
Usability	0.127	4	**0.581**	**0.724**	**0.610**	1.915
Dependability	0.134	4	**0.576**	**0.632**	**0.480**	1.688
Conformance	0.108	5	**0.535**	**0.548**	**0.444**	1.527
Safety	0.137	3	**0.559**	**0.627**	**0.509**	1.695
Economic	0.123	4	**0.556**	**0.523**	**0.401**	1.480
Aesthetics	0.125	5	**0.554**	**0.561**	**0.653**	1.768
Perceived quality	0.121	4	**0.537**	**0.610**	**0.540**	1.687
Actual Level of Performance (Actual LP_j)			4.482	4.884	4.170	13.536

Fig. 6. Process matrix 2—actual level of performance

$$\begin{aligned}
\mathrm{QPI}_{\mathrm{Product}} &= \frac{\text{actual } LP}{\text{max } LP} \times 100\% \\
&= \frac{\text{value in right bottom cell in Fig. 6}}{\text{value in right bottom cell in Fig. 5}} \times 100\% \\
&= \frac{13.536}{17.454} \times 100 \\
&= 77.56\%
\end{aligned}$$

In the example presented by Arditi and Lee (2003), the corporate service quality performance ($\mathrm{QPI}_{\mathrm{Corporate}}$) was measured for a D/B firm while Arditi and Lee (2004) extended this example by measuring the project service quality performance ($\mathrm{QPI}_{\mathrm{Project}}$) of a D/B project. $\mathrm{QPI}_{\mathrm{Corporate}}$ and $\mathrm{QPI}_{\mathrm{Project}}$ were found to be 93.68 and 90.95%, respectively. If the example building described above is the very same project carried out by the very same D/B firm, then the total quality performance can be calculated by making use of the average weights specified by owners, D/B executives, and the quality system assessor ($W_{\mathrm{Corporate}}$= 32.95%, W_{Project}=33.51%, and W_{Product}=33.54%)

$$\begin{aligned}
\mathrm{QPI}_{\mathrm{Total}} &= \mathrm{QPI}_{\mathrm{Corporate}} + \mathrm{QPI}_{\mathrm{Project}} + \mathrm{QPI}_{\mathrm{Product}} \\
&= (W_{\mathrm{Corporate}} \times \mathrm{QPI}_{\mathrm{Corporate}}) + (W_{\mathrm{Project}} \times \mathrm{QPI}_{\mathrm{Project}}) \\
&\quad + (W_{\mathrm{Product}} \times \mathrm{QPI}_{\mathrm{Product}}) \\
&= (32.95\% \times 93.68) + (33.51\% \times 90.95) \\
&\quad + (33.54\% \times 77.56) \\
&= 87.36\%
\end{aligned}$$

Given the relationship in Eq. (7), it is clear that it is desirable for the QPI to be as close to 100% as possible. The real benefit of the QPI becomes apparent when a construction owner compares the QPI of different D/B firms undertaking different projects of different buildings. The QPI is also of value to individual D/B firms who can use it to compare their performance in different products and take measures to maximize their QPI. They can also benchmark themselves against their competitors.

The total quality performance measurement tool is designed as a relational database system using quality function deployment (Sriraman et al. 1990; Doukas et al. 1995). Process Matrices 1 and 2 described in Figs. 3, 5, and 6 are calculated by means of an integrated system designed as an *Excel* spreadsheet.

Conclusion

The total quality performance measurement model reported in this paper was developed as an answer to the need for better quality monitoring in D/B projects. It can be used by a construction owner as a part of a qualification system to rank D/B firms in terms of their total quality performance. It can also be used by D/B firms to improve their quality performance and to benchmark themselves against industry standards.

The total quality performance measurement model is applicable only to D/B firms and projects, since the surveys that investigate owners' needs and expectations and construction executives' views have been conducted only for this type of organization. The first step in this study was the development of a service quality performance measurement model that works at the corporate (Arditi and Lee 2003) and the project (Arditi and Lee 2003) levels. The next and final step involves a product quality performance measurement tool for the constructed facility and is reported in the preceding sections.

References

Akao, Y., and Mizuno, S. (1994). *QFD: The customer-driven approach to quality planning and deployment*, Asian Productivity Organization, Tokyo.

Akao, Y. (1990). *Quality function deployment: Integrating customer requirements into product design*, Productivity, Cambridge, Mass.

Arditi, D., and Lee, D.-E. (2003). "Assessing the corporate service quality performance of design/build contractors using quality function deployment." *Constr. Manage. Econom.*, 21(2), 175–185.

Arditi, D., and Lee, D.-E. (2004). "Service quality performance of design/build contractors using quality function deployment." *Constr. Manage. Econom.*, 22(1), 123–127.

Black, S. A., and Porter, L. J. (1996). "Identification of the critical factors of TQM". *Decision Sciences*, 27(1), 1–21.

Curkovic, S., Vickery, S., and Droge, C. (2000). "Quality-related action programs: Their impact on quality performance and firm performance". *Decision Sciences*, 31(4), 885–905.

Desatnick, R. I. (1992). "Inside the Baldrige award guidelines". *Quality Progress*, 25(12), 69–74.

Design Build Institute of America (DBIA). (1998). The Integrated Service Association ⟨www.DBIA.org⟩ (accessed 2000).

Doukas, L., William, P. W., and Jeyaratnam, C. (1995). "Integrating quality factors into system design." *Proc., 1995 IEEE International Engineering Management Conf.*, Singapore, 235–240.

Garvin, D. A. (1988). *Managing Quality: The strategic and competitive edge*, Harvard Business School Press, Boston.

Hoyle, D. (1998). *ISO 9000 quality systems handbook*, 3rd Ed., Butterworth Heinemann Ltd., Jordan Hill, Oxford, U.K.

Liu, M. A. (2003). "The quest for quality in public housing projects: A behavior-to-outcome paradigm." *Constr. Manage. Econom.*, 21, 147–158.

Parasuraman, A., Zeithaml, V. A., and Berry, L. L. (1985). "A conceptual model of service quality and its implications for future research." *J. Marketing*, 49, 41–50.

Pheng, S. L., and Willie, T. (1996). "Public policies for managing construction quality: The grand strategy of Singapore." *Constr. Manage.*

J. Constr. Eng. Manage., 2006, 132(1): 49-57

Econom., 14(4), 295–309.

Prieser, W. F. E., Rabinowitz, H. Z., and White, E. T. (1988). *Post-occupancy evaluation*, Van Nostrand Reinhold, New York.

Project Management Institute (PMI). (2000). *A guide to the project management body of knowledge*, 2000 Ed., Upper Darby, Pa.

Shillito, M. L. (1994). *Advanced QFD: Linking technology to market and company needs*, Wiley, New York.

Sriraman, V., Tosirisuk, P., and Chu, H. W. (1990). "Object oriented databases for quality function deployment and Taguchi methods." *Comput. Ind. Eng.*, 19(1–4), 285–290.

Wilson, D., and Collier, D. (2000). "An empirical investigation of the Malcolm Baldrige quality framework". *Decision Sciences*, 31(2), 361–390.

Wissema, J. G., and Benes, J. (1980). "A cross-impact case study: The Dutch construction sector." *Future*, 12(5), 394–404.

Yates, J. K. (1995). "Use of design build in *E/C* industry." *J. Manage. Eng.*, 11(6), 33–38.

Zairi, M., and Youssef, M. A. (1995). "Quality function deployment—A main pillar for successful total quality management and product development". *Int. J. Qual. Reliab. Manage.*, 12(6), 9–23.

J. Constr. Eng. Manage., 2006, 132(1): 49-57