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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CE Database subject headings: Quality control; Design/build; Engineering firms; Construction management.

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.

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.
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).
1. Identifying the elements and collecting the data—Fig. 1 shows the data matrix that contains information \((IWi)\) about customer requirements (the WHATs), the technical characteristics \((HHj)\) of the companies providing the product (the HOWs), and the strength of their interrelationships \((Iij)\).

2. Processing of the data in the data matrix—The information in the highlighted column \(\mathcal{S}\) and row \(\mathcal{S}\) 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 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

\[
R_{ij} = \frac{(W_i \times PW_i) + (H_j \times PH_j)}{2} \times I_{ij}
\]

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

\[
\sum_{j=1}^{m} W_j = 1
\]

\[
\sum_{j=1}^{n} H_j = 1
\]

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) for each WHAT, is calculated using the following equation. These values are placed in the right most column of the process matrix in Fig. 2

\[
\text{Max LP} = \sum_{j=1}^{n} R_{ij} \quad \text{for } 1 \leq i \leq m
\]

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

\[
\text{Max LP} = \sum_{i=1}^{m} R_{ij} \quad (1 \leq j \leq n)
\]

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

\[
\text{Max LP} = \sum_{i=1}^{m} \text{Max LP}_i = \sum_{j=1}^{n} \text{Max LP}_j
\]

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:

\[
\text{QPI} = \frac{\text{actual LP} \text{ (from step 4)}}{\text{Max LP} \text{ (from step 3)}} \times 100\%
\]

Measuring Total Quality Performance

The construction industry is characterized(8,84),(994,993)...
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...
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 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. |

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

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

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

<table>
<thead>
<tr>
<th>Building quality factors</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance</td>
<td>The measure to which the primary operating characteristics and functions of the building components meets the building users’ basic functional and technical needs.</td>
</tr>
<tr>
<td>Usability</td>
<td>The degree of fulfillment of an intended usage requirement or reasonable expectations.</td>
</tr>
<tr>
<td>Dependability</td>
<td>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.</td>
</tr>
<tr>
<td>Conformance</td>
<td>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, statutes, and other consideration.</td>
</tr>
<tr>
<td>Safety</td>
<td>The degree to which the risk of harm or damage to building users is limited to an acceptable and/or perceivable level.</td>
</tr>
<tr>
<td>Economics</td>
<td>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.</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>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.</td>
</tr>
<tr>
<td>Perceived quality</td>
<td>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.</td>
</tr>
</tbody>
</table>
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.
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