Available online at www.CivileJournal.org

Civil Engineering Journal

Vol. 6, No. 9, September, 2020

Analyzing Engineering-Related Delays Using Quality Function Deployment in Construction Projects

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Received 27 May 2020; Accepted 14 August 2020

Abstract

This paper presents a methodology for analyzing engineering-related delays in construction projects using Quality Function Deployment (QFD). The steps of the QFD technique are combined in the quality and control policy. A reference matrix based on the literature review is constructed with engineering delays and a survey of all parties involved in construction projects. The QFD matrix aids in identifying the most significant reasons for delays and claims in the construction projects. For the identified reasons, solutions have been developed to limit or reduce them. The mean sources of construction delays include engineering, construction, financial/economic, management/administrative, and force majeure. This paper presents a knowledge-based QFD technique dedicated to engineering-related delays. Three categories of Engineering-related delays are considered in the proposed system. These categories are 1) design development, 2) workshop drawings, and 3) project party's changes delays. The knowledge of the QFD matrix is acquired from literature, Federation International des Ingenious - Conseils (FIDIC) contract forms, domain experts, as well as a questionnaire survey. Three classes of participants (i.e., consultants, contractors, and Employers) have been approached to get their feedback on the cases of engineering-related delays. The proposed approach helps to limit or reduce delays in construction projects caused by the engineer. Accordingly, it was concluded to the most important reasons that led to the delay of construction projects related to the engineer, using QFD.

Keywords: Engineering Delays; Construction Projects; Quality Function Deployment; Questionnaire Survey; FIDIC.

1. Introduction

The construction industry has different characteristics that may lead to delays, which might lead to disputes between the various parties of the project. The flexibility of owners to make changes during the execution phase, the distribution of risks between owners and contractors, and the degree of owner's involvement in the project control during construction time may vary from a procurement strategy to another. The procurement strategy would be more concerned about defining the appropriate project delivery method and selecting the best contract type that suits the project environment and objectives. Delays and claims are common due to the increasing complexity of the construction process. Owners used to transfer the major risks to contractors. These risks include; inflation, accidents, low labor productivity, adverse weather, shortage of materials and skilled labor, and unforeseen site conditions. Thus, construction contracts are becoming more complex. Delays and claims have become a repetitive phenomenon in the construction industry. Such a phenomenon, if not managed efficiently, would hinder the success of many construction projects, and thus slow down the wheel of development.

This research proposed the use of QFD technique as a preventive procedure to reduce engineering delays in construction projects. The use of the QFD matrix improves the quality and reliability of engineer-related work and

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http://dx.doi.org/10.28991/cej-2020-03091582

thus minimizes delays in construction projects that may lead to claims or disputes. The rest of the paper is organized as follows: Section 2 includes the literature review. Then the proposed QFD Methodology is illustrated in detail in Section 3. Section 4 presents the data collection and detailed analysis of the engineering-related key delays. Then the evaluation of the findings is described in Section 5. Finally, the results of this study are concluded in Section 6.

2. Literature Review

Quality function deployment consists of four stages, which are summarized according to previous studies. Product Planning is the first stage in which the user's requirement converted into design specifications. Then, these specifications are prioritized, and the design target values are finalized. The essential characteristics of the product are then published in the next phase of QFD. This matrix is called House of Quality [1]. House of Quality (HOQ) is the first and most significant matrix of QFD explained in the following steps [2]:

- Determine the requirements and needs of users, and then put them in the first column of the matrix [3].
- Assign the priority value next to each of the requirements (degree of importance) by using the Liker scale after making a survey of the users and place those values in a column next to the needs [4].
- The designing team determines the design specifications, which correspond to users' needs. This is considered a significant step in the translation process, as it requires a lot of research and professional expertise in various aspects of designing in order to reach the product characteristics [3].
- Competitive Analysis: set by the user in order to determine which of the designing team has fulfilled needs [5].
- The relationship between design specifications and the requirements of the user (Relationship Matrix) (Figure 3-5): Determined by the designing team where the relationship between the requirements of users and the design specifications is described in the numerical value of (0 =No correlation, 1 =Weak correlation, 3 = Medium correlation,9 = Strong correlation) [6]. Such evaluation is driven by personal experience, user survey results, or data from statistical studies. (Figure 1)
- Correlation among design specifications: (Correlation Matrix) (Figure 2): Designing team determines how each of the design specifications affects the other specifications. The correlation is expressed as a strong positive correlation or a negative correlation relationship. This matrix is utilized less frequently in quality houses. However, it provides great help for designers during the next phase of QFD [7].
- Determine the Importance Weight to specifications of design user requirements in the previous matrix are replaced by the design specifications while the design specifications are replaced by design components [4]: This equals the sum of multiplying the degree of importance to a need by the value of the relationship between that need and the corresponding design specification [8].
- Determine the Relative Weight of the design specification: To evaluate Relative Weight to each of the design specifications, each Importance Weight is divided by total Importance Weight to all specifications then multiplied by 100.

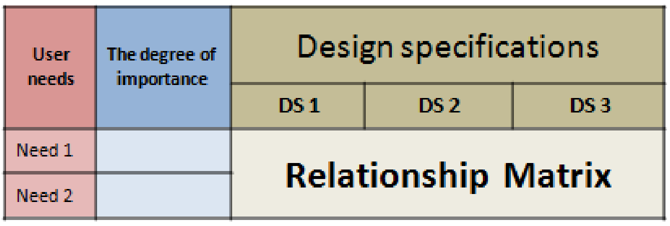

Figure 1. Relationship Matrix (Hery 2015)

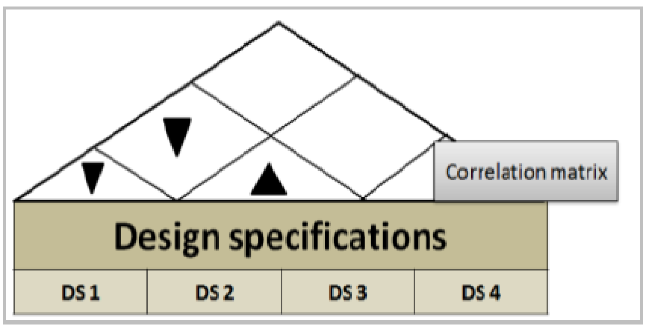

Figure 2. Correlation Matrix (Hery 2015)

Then the Product design stage requires designing team to come up with creative and innovative ideas. The concepts of design re-established in order to achieve target values on a priority basis. Such phase involves the following steps [9]:

- User requirements in the previous matrix are replaced by design specifications, while design specifications are replaced by design components [4].
- The degree of importance of each of the design specifications is are calculated according to the Relative Weight discovered in the first matrix.
- The correlation between design specifications and the design components in the midsection of the matrix is determined by designers [10].
- The Importance weight of each of the design components equals to the sum of multiplying Degree of Importance of any design specifications by Correlation Value of the related Design Components.
- The Relative Weight to each of the Design Components is determined by dividing each Importance Weight of the component by the total Importance Weights to all components then multiplied by 100.

After that, the Process Planning phase in which we identify the work required to prepare each of the components by characterizing the required processes to accomplish our task [11]. Then the Process Control phase where critical control measures are set in order to prevent failure in coordinating with the department of quality assurance to define performance indicators to monitor the production process [12].

2.1. Quality Function Deployment

Quality Function Deployment (QFD) is defined as a method for developing the design quality which aims at satisfying the consumer and then translating the demand of consumer into design targets and major quality assurance points to be used throughout the production phase. QFD can be seen as a process in which the consumer's voice is valued to carry through the whole process of production and services. QFD was invented in Japan by Yoji Akao in 1966 but was first implemented in the Mitsubishi's Kobe shipyard in 1972, possibly out of the teaching of Deming [13]. Then, later it was adopted and developed by other Japanese companies, notably Toyota and its suppliers. The long-term viability of an organization mainly depends on how effectively the organization utilizes its resources to satisfy its stakeholders. For the organizations operating in the construction industry, one of the most privileged stakeholders is the clients (end-users or customers depending on the project type; therefore, in the rest of this research, client, customer, and end-user will be used interchangeably). Satisfying their needs and expectations is of the uttermost importance for the companies because the quality is in the eye of the beholder, and whatever they demand and expect from a product/project defines the quality characteristics of an entity. The unique nature of the industry necessitates the understanding of client needs and expectations for each project carefully for increasing their satisfaction level. Over the past decades, quality has been a differentiating factor within the construction industry. It has been demonstrated that despite the constraints on quality differentiation efforts (like project budget, rules, and regulations, etc.), many companies are competing using quality differentiation strategy and sustaining their competitiveness in the long run [8].

Achievement of client satisfaction necessitates the management of quality systematically, which further requires the utilization of quality tools and techniques for this purpose. Quality function deployment (QFD) is one of these techniques to deal with customer needs and expectations more systematically for achieving the most significant objective of a construction company, satisfaction of clients. QFD is broadly total quality management (TQM) implementation technique requiring a clear assessment of client/end-user expectations apart from the basic needs of a project to convert them into design targets. It is worth noting that Quality Function Deployment (QFD) allows the consideration of the "voice of the customer" along the service development path to market entry [14]. A structured approach of designing, by translating user's requirements into design characteristics during each phase of the product development process [15]. A way to ensure the quality of design when the product is in the design study phase [11]. Methodology to focus on various dimensions of quality during the product design process [7].

2.2. QFD-TECHNIQUE

The QFD technique is based on the analysis of the clients' requirements, which normally are expressed in qualitative terms, such as: "easy to use," "safe," "comfortable," or "luxurious."

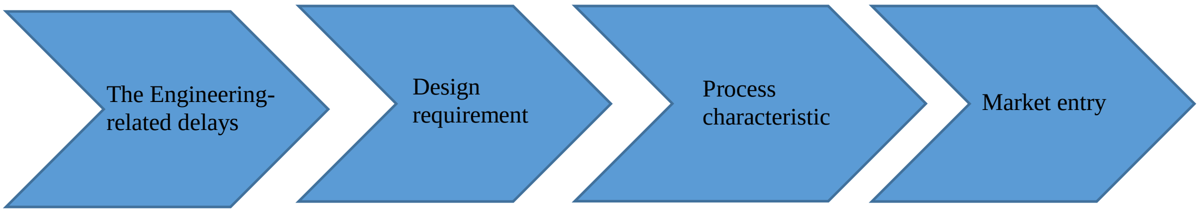

Figure 3. QFD Technique

To develop a service, it is necessary to "translate" these fuzzy requirements into quantitative service design requirements; QFD makes this translation possible [16]. Services are not developed as a whole; instead, these are developed through the integration of different components. The component features are what provide the functionality that, in turn, satisfy client requirements. The firm organization is another factor that effects service development. Unfortunately, the importance of the service development process is not known by all the employees. For this reason, the establishment of an appropriate communication system is particularly important. This system must keep the meaning of the clients´ requirements during the development process [14].

3. QFD Methodology

In this paper, the methodology as follows:

- Develop the customers' requirements list. This study the Engineering-related delays (referred to as the voice of customers or VOC) [17]. It summarizes the Major Categories of Delays and Causes Tables (1 to 8).
- Rank the customers' requirements list (Engineering-related delays). Each customer requirement will be rated according to the causes of the Engineering-related delay (usually, these ratings are assessed based on focus group sessions). The following importance weights are used: 3, 6, and 9 Tables (9 to 13).
- Use quantifiable measures the Engineering-related delays' requirements.
- Define measurement units for technical requirements.
- Identify whether technical requirements correlate with each other. This can be defined in the triangular rooftop matrix (Figure.2). However, it is applicable to assume independence between technical requirements where this part can be dropped.
- Define the correlation between Engineering-related delays and technical requirements by assigning a weighting factor (weak = 1; moderate = 3; strong = 9) in the intersection of each row (Engineering-related delays) with each column (technical requirements). The following symbols are used: "◎ = weak," "O = moderate," and "Δ = strong."
- Determine the relative importance of each technical requirement. For each technical requirement column, the weight rating (1, 2, or 3 of Step 6) is multiplied by the prioritization rating (determined in Step 2) for each of the Engineering-related delays. The sum of each column is written at the bottom of the column. Eldin and Hikle (2003) [1] defined the rest of the steps (Step 8–11) as follows: evaluate the current competition, determine benchmarks, determine target values, and evaluate new related delays. In this study, the findings of the previous steps (Steps 1–7) are used to reduce the Engineering-related delays on the construction projects. The rest of the steps were modified to fit the purpose of this work, as follows:
- Evaluate the current practice of each technical requirement. The technical requirements will be assessed on a Likert scale (ranging from 1 to 5), in which 5 is excellent, 3 is good, 1 is weak.
- Calculate the weights of each technical requirement as the ratio of the column sum (found in Step 7) over the total sum of the technical requirements that belong to its attribute (attribute sum).
- Evaluate the attributes. The weight of the technical requirement (TR) (found in Step 9) and the Likert scale evaluation (found in Step 8) will be used to define the attribute weighted average score (AWAS), as follows:

$$AWASattribute = \sum (TR\ weight \times likert\ scale) \tag{1}$$

- Determine the performance level (excellent, satisfactory, and deficient) for the 8 attributes according to AWAS [excellent (4 ≤ AWAS ≤ 5); satisfactory (3 ≤ AWAS < 4); deficient (1 ≤ AWAS < 3)].

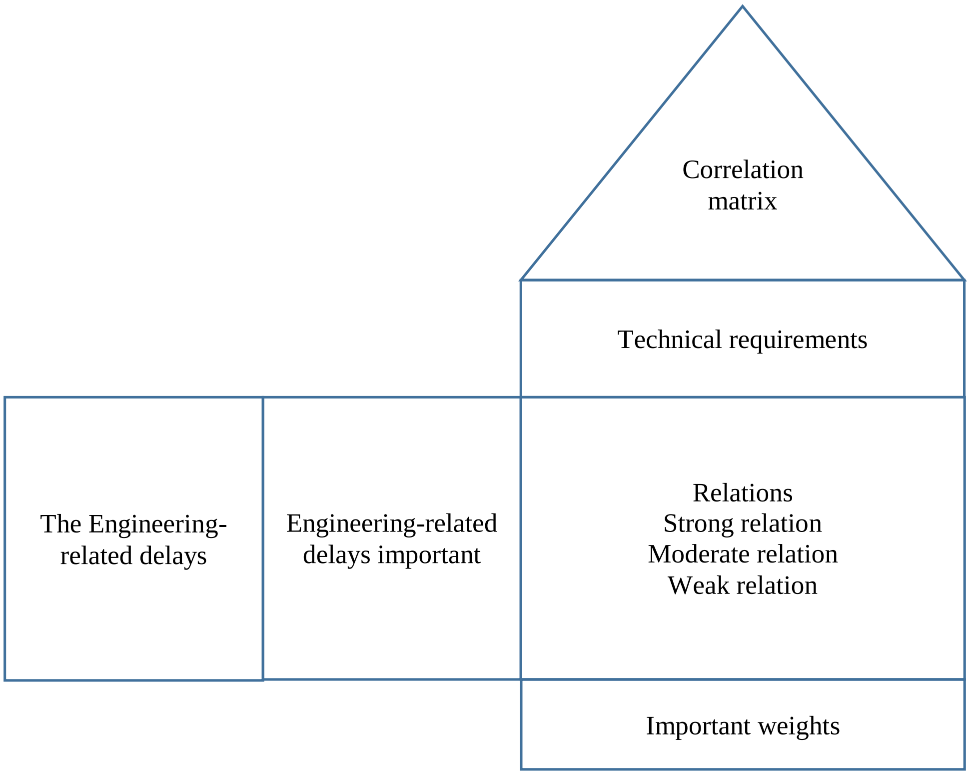

Figure 4. QFD house of quality

3.1. Preparing Tender Documents (Technical Requirements)

Quality function deployment defines technical requirements as elements needed to deliver a product or a service. In this paper, TR is used in a broader sense to include managerial and planning requirements. Technical requirements are organized in the paper at three levels: phases, attributes, and detailed requirements. At the first level, tow (Engineering-related delays) ERD phases are defined: ERD technical written documents, and engineering drawings. However, the definition of ERD phases differs among authors [18, 19]**.** Also, this research Specifies 5 ERD attributes (second level) cascaded down into 36 detailed technical requirements (third level). Table 1 shows the ERD TR hierarchy. The following details are based on the literature survey.

Table 1. Engineering design of the project and preparing tender documents, Technical Requirements Summary

Hierarchy	**Engineering design of the project and preparing tender documents**							
2 phases	Requirements for technical written documents							
	Requirements for special technical specifications and writing							
Attributes	Requirements Specification	Requirements of measurement units approved in the specifications	Requirements Printing	Requirements related to the description of implementation technology and safety requirements	Requirements Price and estimation	Requirements for the Bill of Quantities	Requirements Contract	Requirements for engineering drawings.
	8	3	6	4	4	2	1	8
	28							8
	Total TR 36							

3.1.1. Requirements for Technical Written Documents

The complete Contract specifications consist of an assembly of appropriate standard and one-time-use specifications supplemented by lists and descriptions of items of work and construction details. What design errors: the study errors committed by the engineer during the preparation of any document of competition (technical documents and drawings) of the project.

a) Requirements for special technical specifications and writing

1. Requirements Specification.

Table 2. Requirements technical written documents (Specification)

Requirements (Technical written documents)		Index	Wight	Detailed technical requirements
Special technical specifications and writing	Specification	TR1	3	Materials accurate description and implementation methods
		TR2	3	Specifications clarity and non-generalization
		TR3	3	An exact description of certain characteristics execution
		TR4	3	Possibility of applying the practical specifications of the project
		TR5	3	Clarify the measurement methods used and conform to what is stated in other parts of the other project documents of drawings, drawings, bill of quantities, etc.
		TR6	3	Characterization of test methods for construction materials
		TR7	3	Avoid repetition of Specific work descriptions in two different formats or specifications conflict with other contract documents such as drawings
		TR8	3	Avoid using unknown standard specifications that may lead to misunderstanding

2. Requirements of measurement units approved in the specifications.

Table 3. Requirements technical written documents (Measurement units approved in the specifications)

Requirements (Technical written documents)		Index	Wight	Detailed technical requirements
Special technical specifications and writing	Measurement units approved in the specifications	TR9	3	Avoid contrast and difference in units of measurement considered in different parts of the study
		TR10	3	Clarify what includes the implementation of the unit of measure of work
		TR11	3	Selection of the appropriate measurement unit

3. Requirements Printing, Drafting, and writing.

Table 4. Requirements technical written documents (Printing.)

Requirements (Technical written documents)		Index	Wight	Detailed technical requirements
Special technical specifications and writing	Printing	TR12	3	Review and check the technical conditions after the last printing, especially concerning methods and units of measurement and punctuation marks, etc.
		TR13	2	Divide project work into sections, chapters, and paragraphs properly fit the work received in the project
		TR14	2	Use punctuation correctly
		TR15	2	Avoid using long and weak sentences
		TR16	2	Use understandable and known expressions
		TR17	2	Avoid using general words

4. Requirements were related to the description of implementation technology and safety requirements.

Table 5. Requirements technical written documents (description of implementation technology and safety)

Requirements (Technical written documents)		Index	Wight	Detailed technical requirements
Special technical specifications and writing	Description of implementation technology and safety	TR18	2	Describe construction methods details
		TR19	2	Consider the execution ability method contained in the technical terms
		TR20	2	Description of procedures security and public safety
		TR21	2	Statement of implementation method clearly or in a manner that does not conflict with the rest of the tender documents

b) Requirements Price and estimation

Table 6. Requirements technical written documents (Price and estimation)

Requirements (Technical written documents)	Index	Wight	Detailed technical requirements
Price and estimation	TR22	2	Approve the prices received with the required specifications
	TR23	2	Adequate and detailed price data
	TR24	3	Avoid omission of the analysis or estimate of the price of the material or work required to implement an item
	TR25	3	Avoid contrast and difference between the measurement unit used in pricing in both the Bill of Quantities and the Price Table or the specifications

c) Increments for the Bill of Quantities

Table 7. Requirements technical written documents (Bill of Quantities)

Requirements (Technical written documents)	Index	Wight	Detailed technical requirements
Bill of Quantities	TR26	3	Estimate the correct quantities of project works and avoid the exceeding, more than the specified percentage
	TR27	3	Calculation of quantities based on detailed and final plans

d) Requirements Contract

Table 8. Requirements technical written documents (Contract)

Requirements (Technical written documents)	Index	Wight	Detailed technical requirements
Contract	TR28	3	Avoid the difference between the clauses and terms of the contract and the general conditions

3.1.2. Requirements for Engineering Drawings

Table 9. Requirements for engineering drawings.

	Index	Wight	Detailed technical requirements
Requirements for engineering drawings	TR29	3	Design conforms to the wishes of the project owner or model design criteria
	TR30	3	The design conforms to code requirements
	TR31	3	Construction calculations match (Avoiding calculation errors)
	TR32	3	Avoid differences and inconsistencies among the different drawings (coordination flaw between different drawings: architectural, structural, civil, etc.)
	TR33	3	Operability/constructability problems • Lack of clarity on the construction and implementation mechanism, especially in non-recurrent special construction works, and in reinforcement and maintenance projects
	TR34	3	Scale or dimensional errors
	TR35	3	The need for adequate architectural and construction details to complete the work as required
	TR36	3	Compliance with standards and formalizations of drawing and avoiding errors.

3.2. Engineering-Related Delays (Customers' Requirements)

Table 10. Design development delays

The main source of delay	Index	Importance	Categories of Delays and Causes
Design development delays	ERD1	Strong (weight = 9)	Delay in receiving the design criteria that are needed to start the design process
	ERD2	Strong (weight = 9)	Mistakes/changes in the design criteria provided by the employer
	ERD3	Strong (weight = 9)	Delay in responding to contractor's queries
	ERD4	Strong (weight = 9)	Delay in the approval stage
	ERD5	Strong (weight = 9)	Delay in the design process due to lack of resources, experience, management, etc.
	ERD6	Strong (weight = 9)	Delay due to mistakes in the generated design documents
	ERD7	Strong (weight = 9)	Delay due to unforeseen conditions in design development

Table 11. Workshop drawing submission delays

The main source of delay	Index	Importance	Categories of Delays and Causes
Workshop drawing submission delays	ERD8	Strong (weight = 9)	Delay in receiving design documents that are needed to start the preparation of the workshop drawings process
	ERD9	Strong (weight = 9)	Mistakes/changes in the design documents provided by the employer
	ERD10	Strong (weight = 9)	Delay in responding to contractor's queries
	ERD11	Strong (weight = 9)	Delay in the preparation process due to lack of resources, experience, management, etc.
	ERD12	Strong (weight = 9)	Delay due to unforeseen conditions in shop drawings submission

Table 12. Workshop drawing approval delays

The main source of delay	Index	Importance	Categories of Delays and Causes
Workshop drawing approval delays	ERD13	Strong (weight = 9)	Delay in receiving the needed information to start the review of the workshop drawings process
	ERD14	Strong (weight = 9)	Mistakes/changes in the generated shop drawings
	ERD15	Strong (weight = 9)	Delay in responding to employer's queries
	ERD16	Strong (weight = 9)	Delay in the approval process due to lack of resources, experience, management, etc.
	ERD17	Strong (weight = 9)	Delay due to unforeseen conditions in the approval stage

Table 13. Project parties' changes delays

The main source of delay	Index	Importance	Categories of Delays and Causes
Project parties 'changes delays	ERD18	Strong (weight = 9)	Changes due to mistakes/contradiction and/or constructability problems in the generated design documents
	ERD19	Strong (weight = 9)	Changes in construction procedure due to unforeseen site condition (s)
	ERD20	Strong (weight = 9)	Changes in construction procedure due to soil investigation problem (s)
	ERD21	Strong (weight = 9)	Changes in specifications to save time and/or cost
	ERD22	Strong (weight = 9)	Changes in specifications due to unavailability of materials

4. Data Collection and Analysis

Detailed analysis of the engineering-related key delays is presented as a summary to the knowledge, which had been extracted from the Studies and previous research and also experts in this field. Also, a questionnaire survey had been carried out by the present research writer to ensure the accuracy of the stated summary. Both stages (extracting the knowledge from the previous research and the questionnaire survey) are representing the most important phase in achieving the objectives of the present study since the outcome of these stages represents the core of a QFD-methodology for assessing the delays caused through engineering-related attributes. Also, a detailed analysis of the Requirements for the Engineering design of the project and preparing tender documents, which had been extracted from the Studies and previous research and also experts in this field.

Table 14. Distributed questionnaire sample

Party	No. of Questionnaires
Owners	23
Consultants	23
Contractors	23
Total	69

4.1. Questionnaire Contents

The data included in the questionnaire is divided into four parts. These four parts are:

Part 1: Personal information

Part 2: Organizational information

Part 3: Engineering design of the project and preparing tender documents

Part 4: Engineering-Related Delays (Major Categories of Delays and Causes)

The stakeholders' requirements will be evaluated according to their importance for the ERD program. The researchers suggest three levels of importance with different weights. The levels include Strong (9), Moderate (3), and Weak (1) importance.

Tables 10 to 13 shows four main sources of delay. Engineering-Related Delays with 22 requirements.

5. Evaluation

The findings of the focus groups sessions are summarized as follows:

1. The TRS (Tables 2 to 9) are used as column headings, and the Engineering-Related Delays (ERD) (Table 10 to 13) are used as row headings.
2. At the intersection for each TR (column) and ERD (row), the correlation is evaluated according to three weights (strong = 9; moderate = 3; and weak = 1). The intersection is filled with "◎," "O," and "∆." as shown in Table 15.

Table 15. QFD matrix symbols

Correlation level	Symbol	weight
Strong	◎	9
Moderate	O	3
weak	∆	1

3. For each TR (column), the total weighted correlation is calculated as the sum of products of stakeholder importance and its correlation weight.

$$TRj = \sum_{n=1} (Engineering\ Related\ Delays(ERD) \times \text{correlation weight})j, \quad (2)$$

J = 1, 2, ………, 36

4. The attribute's sum will be the added sum of its consisted TRs

$$Attribute\ \ sum = \sum (TR\ sum) \quad (3)$$

5. The TR weights will be the ratio of TR sum over its attribute sum

$$TR\ weight = \frac{TR\ sm}{Attribute\ \ sum} \quad (4)$$

For each attribute, the total of its consisting TR weights will be 1. Tables 15(A) to 15(C) show the QFD matrices

6. The TRs is evaluated according to the Likert scale (ranging from 1 to 5); the research assessed the 32 technical requirements, where 5 is excellent, 4 is very good, 3 is good, 2 is fair, and 1 is poor.
7. The AWAS is calculated for 10 attributes;

$$AWAS_{attibute} = \sum (\text{TR wight} + \text{likert scale}) \quad (5)$$

8. A performance level (excellent, satisfactory, or deficient) is determined for the 10 attributes based on the AWAS, as described in Table 16.

Table 16. Evaluation Levels Based on AWAS

AWAS	Evaluation level
$4 \leq AWAS \leq 5$	1 (excellent)
$3 \leq AWAS < 4$	2 (satisfactory)
$1 \leq AWAS < 3$	3 (deficient)

Table 18 shows the evaluation output of AWAS and the performance levels of the attributes for the being studied.

Table 17(A). Correlation matrix

ERD main source of delay	Index	Categories of Delays and Causes	Importance	Technical Requirements										
				Requirements for technical written documents										
				Requirements for special technical specifications and writing										
				Requirements for special technical specifications and writing										
				Requirements Specification.								Requirements Measurement units approved in the specifications		
				TR1	TR2	TR3	TR4	TR5	TR6	TR7	TR8	TR9	TR10	TR11
	1	Delay in receiving the design criteria that are needed to start the design process.	9	△	△	△	△	△	△	△	△	△	△	△
	2	Mistakes/changes in the design criteria provided by the employer.	9	◎	O	◎	◎	◎	O	O	O	△	△	△
	3	Delay in responding to contractor's queries.	9	◎	O	◎	◎	O	O	◎	◎	◎	◎	O
	4	Delay in approval stage.	9	O	O	O	O	O	O	O	O	O	O	O
	5	Delay in the design process due to lack of resources, experience, management, etc.	9	△	△	△	△	△	△	△	△	△	△	△
	6	Delay due to mistakes in the generated design documents.	9	◎	◎	◎	◎	◎	O	◎	◎	◎	O	O
	7	Delay due to unforeseen conditions in design development.	9	△	△	△	△	△	△	△	△	△	△	△
	8	Delay in receiving design documents that are needed to start the preparation of the workshop drawings process.	9	O	△	△	△	△	△	△	△	△	△	△
	9	Mistakes/changes in the design documents provided by the employer.	9	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
	10	Delay in responding to contractor's queries.	9	◎	O	◎	◎	O	O	◎	◎	◎	◎	
	11	Delay in the preparation process due to lack of resources, experience, management, etc.	9	◎	◎	O	O	O	O	O	◎	O	O	O
	12	Delay due to unforeseen conditions in shop drawings submission.	9	△	△	△	O	△	△	△		△	△	△
	13	Delay in receiving the needed information to start the review of the work shop drawings process	9	O	O	O	O	O	O	O	O	O	O	O
	14	Mistakes/changes in the generated shop drawings	9	◎	◎	◎	◎	◎		◎	◎	◎	◎	◎
	15	Delay in responding to employer's queries.	9	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
	16	Delay in the approval process due to lack of resources, experience, management, etc.	9	O	◎	O	O	O	O	O	◎	◎	O	O
	17	Delay due to unforeseen conditions in approval stage	9	△	△	△	△	△	△	△	△	△	△	△
	18	Changes due to mistakes/contradiction and/or constructability problems in the generated design documents.	9	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
	19	Changes in construction procedure due to unforeseen site condition(s)	9	O	O	◎	◎	◎	◎	◎	◎	◎	O	△
	20	Changes in construction procedure due to soil investigation problem(s).	9	◎	◎	◎	◎	◎	◎	◎	◎	◎	△	△
	21	Changes in specifications in order to save time and/or cost.	9	◎	◎	◎	◎	◎	◎	◎	◎	◎	O	△
	22	Changes in specifications due to unavailability of materials	9	◎	◎	◎	◎	◎	◎	◎	◎	◎	O	△

Table 17(B). Correlation matrix

Erd main source of delay	Index	Categories of Delays and Causes	Importance	Technical Requirements									
				Requirements for technical written documents									
				Requirements for special technical specifications and writing									
				Requirements Printing						Requirements related to the description of implementation technology and safety requirements			
				TR12	TR13	TR14	TR15	TR16	TR17	TR18	TR19	TR20	TR21
	1	Delay in receiving the design criteria that are needed to start the design process.	9	○	○	○	○	○	○	○	△	△	○
	2	Mistakes/changes in the design criteria provided by the employer.	9	○	△	△	△	△	△	○	○	○	○
	3	Delay in responding to contractor’s queries.	9	○	○	○	○	○	○	○	○	○	○
	4	Delay in approval stage.	9	◎	○	◎	○	○	△	◎	○	○	◎
	5	Delay in the design process due to lack of resources, experience, management, etc.	9	△	△	△	△	△	△	△	△	△	△
	6	Delay due to mistakes in the generated design documents.	9	◎	○	○	◎	◎	◎	◎	◎	△	◎
	7	Delay due to unforeseen conditions in design development.	9	△	△	△	△	△	△	△	△	◎	△
	8	Delay in receiving design documents that are needed to start the preparation of the workshop drawings process.	9	○	△	△	△	△	△	△	△	◎	△
	9	Mistakes/changes in the design documents provided by the employer.	9	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
	10	Delay in responding to contractor’s queries.	9	○	○	○	○	○	○	○	○	○	○
	11	Delay in the preparation process due to lack of resources, experience, management, etc.	9	○	△	△	△	△	△	○	○	○	△
	12	Delay due to unforeseen conditions in shop drawings submission.	9	△	△	△	△	△	△	○	○	◎	△
	13	Delay in receiving the needed information to start the review of the work shop drawings process	9	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
	14	Mistakes/changes in the generated shop drawings	9	○	○	○	○	○	○	◎	◎	◎	◎
	15	Delay in responding to employer’s queries.	9	◎	○	○	○	○	○	◎	◎	◎	◎
	16	Delay in the approval process due to lack of resources, experience, management, etc	9	○	△	△	△	△	△	○	○	○	○
	17	Delay due to unforeseen conditions in approval stage	9	△	△	△	△	△	△	○	○	○	○
	18	Changes due to mistakes/contradiction and/or constructability problems in the generated design documents.	9	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
	19	Changes in construction procedure due to unforeseen site condition(s)	9	◎	◎	△	△	△	△	△	◎	◎	◎
	20	Changes in construction procedure due to soil investigation problem(s).	9	◎	△	△	△	△	△	△	◎	◎	◎
	21	Changes in specifications in order to save time and/or cost.	9	◎	△	○	○	○	○	◎	◎	◎	◎
	22	Changes in specifications due to unavailability of materials	9	◎	△	○	○	○	○	◎	◎	◎	◎

Table 17(C). Correlation matrix

Erd main source of delay	Index	Categories of Delays and Causes	Importance	Technical Requirements						
				Requirements for technical written documents						
				Requirements for special technical specifications and writing						
				Requirements Price and estimation				Requirements for the Bill of Quantities		Requirements Contract
				TR22	TR23	TR24	TR25	TR26	TR27	TR28
	1	Delay in receiving the design criteria that are needed to start the design process.	9	◎	◎	◎	◎	△	△	○
	2	Mistakes/changes in the design criteria provided by the employer.	9	◎	◎	◎	◎	○	○	◎
	3	Delay in responding to contractor's queries.	9	◎	◎	◎	◎	○	○	◎
	4	Delay in approval stage.	9	◎	◎	◎	◎	◎	◎	◎
	5	Delay in the design process due to lack of resources, experience, management, etc.	9	○	○	○	○	◎	◎	◎
	6	Delay due to mistakes in the generated design documents.	9	◎	◎	◎	◎	◎	○	◎
	7	Delay due to unforeseen conditions in design development.	9	△	△	△	△	△	△	△
	8	Delay in receiving design documents that are needed to start the preparation of the workshop drawings process.	9	△	△	△	△	△	△	△
	9	Mistakes/changes in the design documents provided by the employer.	9	◎	◎	◎	◎	◎	◎	◎
	10	Delay in responding to contractor's queries.	9	◎	◎	◎	◎	◎	◎	◎
	11	Delay in the preparation process due to lack of resources, experience, management, etc.	9	◎	◎	◎	◎	◎	◎	◎
	12	Delay due to unforeseen conditions in shop drawings submission.	9	△	○	△	△	○	○	○
	13	Delay in receiving the needed information to start the review of the work shop drawings process	9	○	○	○	○	○	○	○
	14	Mistakes/changes in the generated shop drawings	9	◎	◎		◎	◎	◎	◎

Table 17(D). Correlation matrix

Erd main source of delay	Index	Categories of Delays and Causes	Importance	Technical Requirements							
				Requirements for engineering drawings.							
				TR29	**TR30**	**TR31**	**TR32**	**TR33**	**TR34**	**TR35**	**TR36**
	1	Delay in receiving the design criteria that are needed to start the design process.	9	○	○	○	○	○	○	○	○
	2	Mistakes/changes in the design criteria provided by the employer.	9	◎	◎	○	○	◎	○	○	○
	3	Delay in responding to contractor's queries.	9	○	○	◎	◎	◎	◎	◎	○
	4	Delay in approval stage.	9	◎	◎	◎	◎	◎	◎	◎	◎
	5	Delay in the design process due to lack of resources, experience, management, etc.	9	△	○	△	○	○	△	△	○
	6	Delay due to mistakes in the generated design documents.	9	○	◎	◎	◎	◎	◎	◎	◎
	7	Delay due to unforeseen conditions in design development.	9	△	△	△	△	△	△	△	△
	8	Delay in receiving design documents that are needed to start the preparation of the workshop drawings process.	9	◎	◎	◎	◎	○	○	○	○
	9	Mistakes/changes in the design documents provided by the employer.	9	○	◎	◎	◎	◎	◎	◎	◎
	10	Delay in responding to contractor's queries.	9	○	○	◎	◎	◎	◎	◎	◎
	11	Delay in the preparation process due to lack of resources, experience, management, etc.	9	◎	◎	◎	◎	◎	◎	○	○
	12	Delay due to unforeseen conditions in shop drawings submission.	9	△	△	△	△	△	△	△	△
	13	Delay in receiving the needed information to start the review of the work shop drawings process	9	○	○	○	○	○	○	○	○
	14	Mistakes/changes in the generated shop drawings	9	◎	◎	◎	◎	◎	◎	◎	◎
	15	Delay in responding to employer's queries.	9	◎	◎	◎	◎	◎	◎	◎	◎
	16	Delay in the approval process due to lack of resources, experience, management, etc.	9	◎	◎	◎	◎	◎	◎	◎	◎
	17	Delay due to unforeseen conditions in approval stage	9	△	△	△	△	△	△	△	△
	18	Changes due to mistakes/contradiction and/or constructability problems in the generated design documents.	9	◎	◎	◎	◎	◎	◎	◎	◎
	19	Changes in construction procedure due to unforeseen site condition(s)	9	○	○	○	○	◎	○	○	○
	20	Changes in construction procedure due to soil investigation problem(s).	9	○	◎	○	◎	◎	○	○	○
	21	Changes in specifications in order to save time and/or cost.	9	○	◎	◎	◎	◎	○	◎	◎
	22	Changes in specifications due to unavailability of materials	9	○	◎	◎	◎	◎	○	◎	◎
		TR SUM		9324							
		weight		0.102	0.133	0.131	0.139	0.145	0.114	0.120	0.116

Table 18. An Evaluation for Engineering-Related Delays

Index	Technical Requirements Summary	T.R weight	Likert scale rating		AWAS	level
TR1	Materials accurate description and implementation methods.	0.131687	5	0.658436	4.895062	1
TR2	Specifications clarity and non-generalization.	0.117284	5	0.58642		
TR3	Exact description of certain characteristics execution	0.12963	5	0.648148		
TR4	Possibility of applying the practical specifications of the project	0.13786	5	0.6893		
TR5	Clarify the measurement methods used and conform to what is stated in other parts of the other project documents of drawings, drawings, bill of quantities, etc.	0.117284	5	0.58642		
TR6	Characterization of test methods for construction materials.	0.104938	4	0.419753		
TR7	Avoid repetition of Specific work descriptions in two different formats or specifications conflict with other contract documents such as drawings.	0.123457	5	0.617284		
TR8	Avoid using unknown standard specifications that may lead to misunderstanding	0.13786	5	0.6893		
TR9	Avoid contrast and difference in units of measurement considered in different parts of the study.	0.449275	5	2.246377	4.449275	1
TR10	Clarify what includes the implementation of the unit of measure of work.	0.311594	4	1.246377		
TR11	Selection of the appropriate measurement unit.	0.23913	4	0.956522		
TR12	Review and check the technical conditions after the last printing, especially for methods and units of measurement and punctuation marks, etc.	0.258772	5	1.29386	3.219298	2
TR13	Divide project work into sections, chapters, and paragraphs properly fit the work received in the project.	0.149123	3	0.447368		
TR14	Use punctuation correctly.	0.149123	3	0.447368		
TR15	Avoid using long and weak sentences.	0.149123	2	0.298246		
TR16	Use understandable and known expressions	0.149123	2	0.298246		
TR17	Avoid using general words.	0.144737	3	0.434211		

Table 19. An Evaluation for Engineering-Related Delays

Index	Technical Requirements Summary	T.R weight	Likert scale rating		AWAS	level
TR18	Describe construction methods details.	0.214286	2	0.428571	2.537815	3
TR19	Consider the execution ability method contained in the technical terms.	0.247899	2	0.495798		
TR20	Description of procedures security and public safety.	0.277311	3	0.831933		
TR21	Statement of implementation method clearly or in a manner that does not conflict with the rest of the tender documents.	0.260504	3	0.781513		
TR22	Approve the prices received with the required specifications.	0.256318	2	0.512635	3.718412	2
TR23	Adequate and detailed price data.	0.256318	3	0.768953		
TR24	Avoid omission of the analysis or estimate of the price of the material or work required to implement an item.	0.241877	5	1.209386		
TR25	Avoid contrast and difference between the measurement unit used in pricing in both the Bill of Quantities and the Price Table or the specifications.	0.245487	5	1.227437		
TR26	Estimate the correct quantities of project works and avoid the exceeding, more than the specified percentage.	0.524194	5	2.620968	5	1
TR27	Calculation of quantities based on detailed and final plans.	0.475806	5	2.379032		
TR28	Avoid the difference between the clauses and terms of the contract and the general conditions	1	4	4	4	1
TR29	Design conforms to the wishes of the project owner or model design criteria.	0.102317	5	0.511583	4.220077	1
TR30	The design conforms to code requirements.	0.133205	5	0.666023		
TR31	Construction calculations match (Avoiding calculation errors).	0.131274	3	0.393822		
TR32	Avoid differences and inconsistencies among the different drawings (coordination flaw between different drawings: architectural, structural, civil ... etc.)	0.138996	4	0.555985		
TR33	Operability/constructability problems • Lack of clarity on the construction and implementation mechanism, especially in non-recurrent special construction works, and in reinforcement and maintenance projects.	0.144788	4	0.579151		
TR34	Scale or dimensional errors	0.1139	4	0.455598		
TR35	The need for adequate architectural and construction details to complete the work as required.	0.119691	4	0.478764		
TR36	Compliance with standards and formalizations of drawing and avoiding errors.	0.11583	5	0.579151		

Table 20. Attributes assessment summary

Engineering design of the project and preparing tender documents			AWAS	Assessment		
				Level 1 (excellent)	**Level 2 (satisfactory)**	**Level 3 (deficient)**
Technical written documents	Special technical specifications and writing	Specification	4.89	×	–	–
		Measurement units approved in the specifications	4.45	×	–	–
		Printing	3.22	–	×	–
		Description of implementation technology and safety requirements	2.54	–	–	×
	Price and estimation.		3.72	–	×	–
	Bill of Quantities		5	×	–	–
	Contract		4	×	–	–
Engineering drawings			4.22	×	–	–

Table 21. Actions to improve tender documents

Attribute			**Detailed technical**
Technical written documents	Special technical specifications and writing	Printing	Review and check the technical conditions after the last printing, especially for methods and units of measurement and punctuation marks, etc.
			Divide project work into sections, chapters, and paragraphs properly fit the work received in the project.
			Use punctuation correctly.
			Avoid using long and weak sentences.
			Use understandable and known expressions
			Avoid using general words.
		Description of implementation technology and safety requirements	Describe construction methods details.
			Consider the execution ability method contained in the technical terms.
			Description of procedures security and public safety.
			Statement of implementation method clearly or in a manner that does not conflict with the rest of the tender documents.
	Price and estimation		Approve the prices received with the required specifications.
			Adequate and detailed price data.
			Avoid omission of the analysis or estimate of the price of the material or work required to implement an item.
			Avoid contrast and difference between the measurement unit used in pricing in both the Bill of Quantities and the Price Table or the specifications.

6. Conclusions

Accordingly, through our study of claims in this research and through the QFD matrix, we can categorize these most influential claims to:

✓Technical Documents Claims

Several errors may be made during the preparation of project technical documents, subsequently causing several claims. These claims are divided by nature into the following:

A. Claims of special technical specifications and writing.

B. Price claims and estimates.

C. Claims for the Bill of Quantities.

D. Contract Claims.

These claims are due to errors in the writing and preparation of these specifications. However, for different specification errors, we will review these errors by classifying them into the following:

A-1 Specifications errors include

- Misrepresentation of materials and methods of implementation.
- Ambiguity and generalization in specifications.
- Lack of descriptive information.
- It is not possible to apply the specifications in practice in the circumstances of the project for various reasons.
- Failure to clarify the methods of measurement used and the inconsistency with what is stated in the rest of the other tender documents of the drawings, tables, and quantities.
- Do not describe the testing methods for construction materials to obtain the necessary resistors or specifications.
- Reference to the use of a particular brand without mentioning information related to the quality or technical characteristics of the material.
- Duplicate a description of a particular work with two different shapes or conflicting specifications with other contract documents such as schemas.
- Use unknown standard specifications leads to misunderstanding.

A-2 Errors of units measurement approved in the specifications include:

- Variation and contrast in units of measurement in different parts of the study.
- Do not indicate what the implementation of the unit of measurement involves
- Do not choose the appropriate unit of measurement.

A-3 Typographical errors:

- It results from the non-revision of the technical conditions and their revision after the last printing, especially concerning measurement methods, units, punctuation marks, etc.

A-4 Drafting and writing errors: It includes many errors, the most important ones

- Do not divide the project works into sections, chapters, and professional paragraphs properly-suited to work contained in the project.
- Do not use punctuation correctly (dot, semicolon, and comma).
- Use longitudinal and slender sentences and the frequent use of pronouns, making it difficult to understand sentence and purpose. It is preferable to use short and useful sentences that can perform the desired purpose.
- Use modern terms and terms that are not known and understood by everyone.
- Use general terms: best species, the best races, etc. Instead, it is preferable to use the language of numbers based on the physical and mechanical properties of the materials.

A-5 Claims related to the description of implementation technology and safety requirements

A-6 claims related to the description of implementation technology and safety conditions:

B- Claims due to price estimation errors or cost include (and may fall under other claims)

- Incompatibility of prices received with the required specifications.
- The price of vocabulary is insufficient and not detailed.
- Omission to analyze or estimate the price of a material or work required to implement an item.
- There are contrast and difference between the measurement unit used in the pricing in both the Bill of Quantities and the price table or the specifications.
- The price unit is not included in the price table and its incompatibility with technical conditions or specifications.
- The Issue of loading the price (a price or lump sum).

In most of the files or documents of these projects, we found differences between the contents of the various documents of the contract, which gives many possibilities for interpretation and interpretation, which led to the creation of various financial claims for the parties to the contract.

6.1. Limitations and Future Research

Despite the contributions of this work, there are two limitations. The first is that this study is ambitious in scope and scale but still subjected to restrictions in terms of time and access. The second limitation is that it would be beneficial to track further in time the implementation and to analyze its impact on the overall service quality. Regarding the potential future research, the author highly recommends the usage of QFD within innovative construction projects to prepare construction project documents to limit or reduce delays in construction projects.

7. Conflicts of Interest

The authors declare no conflict of interest.

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