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A Holistic Framework for Assessing the Quality of Building Construction in Saudi Arabia

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Abstract: In order to make sure that structures adhere to the necessary norms and laws, it is essential to evaluate the quality of building construction. According to several frameworks, the quality of a building's construction can be assessed in a number of different circumstances. In order to provide building projects with excellent quality and competitive pricing, hard work is required. To raise the standard of building construction, a model was created. The goal of this project is to provide a model for raising building construction quality. This study used the analytical hierarchy process (AHP) technique, which includes the determination of consistency ratios, pairwise comparisons, normalization, and a comparison matrix. The difficulty of implementing quality was determined for each task using the AHP technique. This was multiplied by the quality factor to obtain the final quality level. The model was tested in three different situations, and it was discovered that quality application is challenging across all building operations. Using a quality evaluation technique, this study assessed the building construction quality in Saudi Arabia. Additionally, a pairwise comparison, normalization, and a comparison matrix were used to calculate the consistency ratio. The ultimate quality level was determined by multiplying the difficulty level for each activity, as determined using the AHP approach, by the quality factor. This study will therefore be helpful to those involved in Saudi Arabian building, including architects, engineers, quality experts, and others. Additionally, the tool aids in the decision making process for enhancing construction quality.

Keywords: building; quality; construction; assessment; Saudi Arabia; AHP; framework

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1. Introduction

The quality of building construction has always been a concern for architects, engineers, and construction professionals. Building construction projects are complex, and they involve various stakeholders and factors that impact the quality of the final product [1–5]. In Saudi Arabia, building construction projects are a crucial part of the national development plan, and they contribute significantly to the country's economic growth. However, ensuring that building construction projects meet the required quality standards is a challenging task, and there is a need for a comprehensive framework to assess the quality of building construction [6].

Government spending on infrastructure from 2008 to 2013 was estimated at USD 574.7 billion; the construction industry in Saudi Arabia has experienced a boom over the last 30 years. Prince Dr. Turki Al Saud (2015) and the President of the King Abdelaziz City for Science and Technology (KACST) reported that the Kingdom's building and construction industry ranks second after the petroleum industry in contributing to gross sector GDP (domestic production). The higher purchasing rate has made the Saudi construction sector the highest Middle Eastern market and is expected to contribute to much of the region's

growth by 2015. Saudi Arabia is also considered one of the world's top per capita spending nations, as shown in Figure 1.

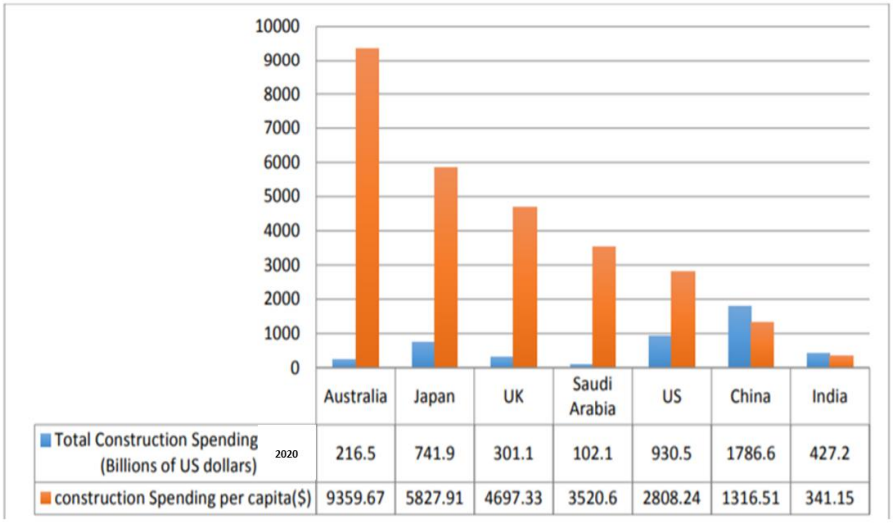


Figure 1. Construction spending per capita [6].

The key considerations affecting consumers have long been recognized as quality, cost, and time [7]. However, the cost and time parameters of the project are often taken for granted in most projects. Moreover, insufficient consideration has been paid to the quality parameter. The need for quality management systems has been recognized for a long time, and many systems and methodologies have been developed and implemented [8]. The difficulties associated with the precise concept of quality are also a result of the problems related to quantification and quality measurement. Any attempt to quantify quality should therefore begin with the concept of quality and the determination of quality attributes. As noted earlier, the concept of quality in the construction industry is related to the satisfaction of the customer and the implementation of a quality management system is a crucial instrument in managing the objective of customer satisfaction consistently and reliably [9]. In addition, quality is defined as adherence to specifications. From the customers' standpoint, all of the concepts provided above describe consistency. Quality can basically be interpreted as "meeting the standards of the consumer". These meanings suggest that the customer's needs must first be defined, and that the "bottom line" to achieving consistency is the satisfaction of those needs. For building organizations, quality is characterized as meeting the owner's criteria for functional adequacy and completion of the construction project on schedule and under budget. In order to execute professional building programs, the building industry has various challenges, since it requires a variety of careers, trades, and associations. The quality of service provided by advisors has often been a focus of considerable inquiry, as well as the effect of poor quality professional services on the quality of a construction project [10].

One of the Kingdom's most important goals in Vision 2030 is to expand the circle of trade activities, contributed to by raising local production capacity to build high-quality and cost-competitive housing [11]. As quality has become a major business priority across the globe, several organizations have started to enforce principles and requirements. The launch of the ISO 9000 series in 1987 has become a global standard for organizations, regardless of their sizes and goods for quality control. In providing quality building projects, the construction industry faces many issues because it involves many occupations and organizations [9]. Quality is the most important criteria in assessing the condition of buildings during construction work. After interviewing quality managers in Saudi Arabia, it was found that there is not a clear system for measuring the quality level of building construction work. Therefore, this research aims to close the gap by developing a model to measure the quality level of buildings under construction.

Building construction is a vital aspect of any country's economy and infrastructure development. In Saudi Arabia, the construction industry has been experiencing rapid growth due to the increasing demand for commercial and residential buildings. However, despite the significant investments made in the construction sector, there have been concerns about the quality of building construction in Saudi Arabia. This is particularly important because poor construction quality can lead to safety hazards, structural defects, and higher maintenance costs. In addition, assessing the quality of building construction is critical for ensuring that buildings meet the required standards and regulations. There are several existing frameworks for evaluating the quality of building construction in different contexts. However, there is a need for a specific evaluation framework that considers the unique characteristics of building construction in Saudi Arabia, such as the extreme weather conditions, availability of materials, and cultural aspects.

Therefore, this research aims to develop an evaluation framework that considers the specific context of building construction in Saudi Arabia. The proposed framework includes factors such as design, materials, project management, and construction processes. By evaluating these factors, the framework helps to identify areas for improvement in building construction quality and provide a systematic approach for ensuring that buildings meet the required standards. Hence, this research is essential because it addresses a current gap in knowledge and provides a practical tool for assessing the quality of building construction in Saudi Arabia. The framework will be useful for building owners, contractors, and regulatory authorities in evaluating the quality of construction projects and making informed decisions. Additionally, the research findings contribute to the body of knowledge in the construction industry and provide insights into the unique challenges and opportunities for building construction in Saudi Arabia.

In order to ensure a systematic and standardized approach to gathering data for this research, the Construction Specifications Institute (CSI) MasterFormat was selected as the framework for organizing and categorizing information related to building construction. The CSI MasterFormat is widely used in the construction industry and provides a comprehensive system for organizing construction documents and specifications. This system includes 50 divisions that cover various aspects of construction, such as site preparation, concrete, masonry, and electrical systems. By utilizing this framework, the data collected in this research are consistent, structured, and easily accessible for analysis. Additionally, the CSI MasterFormat was selected because it is compatible with other industry standards and codes, making it a reliable and widely recognized tool for construction documentation. Use of this framework provides a strong foundation for the evaluation framework proposed in this research, ensuring that the data collected is comprehensive and relevant to the specific context of building construction in Saudi Arabia.

2. Literature Review

This section is divided into two main subsections as following:

2.1. Theoretical Background

2.1.1. Quality Measurement History (ISO 9000)

As consistency became a major focus of industry globally, criteria and protocols began to be followed by numerous organizations. In 1987, the ISO 9000 series was launched and has since become a global quality control standard for organizations, regardless of their sizes and goods. ISO 9000 is a set of recommendations for businesses developing their quality processes [10].

2.1.2. Definition of Quality

Quality as "The totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs". Quality is understood differently by different people and different organizations. Quality is probably the best way of assuring customer loyalty, the best deference against foreign competition, and the only way to secure

continuous growth and profit to difficult market conditions. In order to manage quality, the starting point for the organization is to understand the meanings of the term "quality". Quality is defined as a need for conformance to requirements [10].

2.1.3. Quality Measurement Attributes

Many quality control methods, processes, and methodologies have been developed by different scholars considering the importance of quality in the construction industry. In three ways, they have also classified quality attributes: quality in the view of architects, quality in the view of the customer, and quality in the view of third parties. The significance of and problems associated with quality measurement were illustrated by the authors. Critical factors impacting the progress and failure of building schemes were identified. Initially, the writers shortlisted 55 characteristics impacting the efficiency of building projects. The questionnaire survey accompanied by a response review demonstrated the expertise of the project manager, managerial assistance, participant input, and participant engagement as important project success drivers [12].

2.1.4. Analytical Hierarchy (AHP) Technique

The analytical hierarchy method is a multi-attribute decision making management process that transforms large problems into a set of smaller problems, making it easier to implement. The primary objective of AHP is the computation of factor/attribute weights. Upon organizing attributes on the basis of their dependencies, a pairwise comparison matrix was established in which attributes were organized by assigning scores on a scale of 1–9 in decreasing order of their meaning: 1 means equally significant; 9 means extremely important. Attribute normalization was achieved by dividing the matrix score by the column sum of the reference matrix. The average of each normalized matrix row provides the amount of the respective attribute priority or factor evaluation. Validation of attribute weights was conducted by measuring the accuracy ratio. If the consistency ratio is smaller than or equal to 0.10, the assigned strength numbers are otherwise consistent [12].

2.1.5. Work Breakdown Structure (WBS) Technique

WBS is a hierarchical decomposition of the overall scope of work to be carried out during the project in order to achieve the priorities of the project and produce the deliverables needed. The overall project scope is structured and specified using WBS. The planned work is contained within the lowest level of WBS components, which are called work packages. A work package can be used to group the activities where work is scheduled and estimated, monitored, and controlled. In the context of the WBS, work refers to work products or deliverables that are the result of activity and not to the activity itself [13].

2.1.6. Tool Quantification of the Quality Attributes

Having defined quality attributes from three points of view, a procedure was used to calculate the degree of significance of each attribute separately and in comparison to other attributes. In order to evaluate the significance degree of each value, a 5-scale method (1 = least, 5 = most) was used, as seen in Figure 2. The figures surrounding human characteristics were also included [8].

2.1.7. Construction Process Quality Control

During the building process, quality management of systematic, real-time, and efficient interventions needs to be carried out. In order to accomplish these control goals, the supervisor has to carry out successful surveillance before and after monitoring, and to coordinate a number of control process steps, such as administration, coordination, technology used to demonstrate the building process management system, and several associated steps of quality control [14].

CSI format	
division #	NAME
division 1	GENRAL REQUIREMENT 0.2
division 2	SITE CONSTRUCTION 0.2
division 3	CONCRETE WORK 0.3
division 4	MASONRY 0.4
division 5	METALS 0.5
division 6	WOOD AN PLASTICS 0.6
division 7	THERMAL MOSTURE PROTECTION 0.7
division 8	DOOR WINDOWS 0.8
division 9	FINSHES 0.9
division 10	SECIALTES 10
division 11	EQUIPMEMT 11
division 12	FURNISHINGS 12
division 13	SPECIAL CONSTRUCTION 13
division 14	CONVRIYING SYSTEM 14
division 15	MECHANICAL 15
division 16	Electriacal ELECTRIACAL 16

Figure 2. CSI format.

2.2. Previous Work

Ashtiani et al. [15] worked on the building construction quality index (BCQI), a method created and used in their report. BCQI, the built index, can be used to review the quality standard of building projects and to benchmark potential quality improvement. The built index is also used to compare the standards of building projects. Their research adopted a literature review, data collection questionnaire surveys, and application of the developed model to assess the construction quality of construction projects. To evaluate weights of construction quality attributes, the analytical hierarchy method (AHP) was adopted. Since quality affects various aspects of project management, improving quality assessment in turn enhances project management team decision making. The study helped to enhance quality measurement systems for construction in developing countries. Furthermore, in their study, Nguyen Ngoc et al. [16] put forward a three-tier multicriteria decision making model to evaluate the competitiveness and benchmarking of construction companies. Their model addresses a wide range of crucial factors and attributes that encompass various aspects of the current competitive market.

Khosrowshahi et al. [9] explored quality from different perspectives and laid the basis for the creation, in terms of its constituent attributes, of a concrete concept of quality and its calculation in a quantified way. The work put together a set of quality-related attributes using a systematic literature review and validation through a questionnaire and grouped them under a variety of categories. The work developed a methodology for a more objective measurement and quantification of quality, encompassing measurable as well as subjective attributes of quality. This was carried out using a bidirectional ranking system applied to the attributes of quality. Their research contributes towards the creation of a three-dimensional project strategy space, which can be used for the assessment of project results. Moreover, Ali and Rahmat [10] pointed out the advantages of introducing the ISO 9000 standard for construction companies and the parameters used to assess the performance of projects. The data were collected using a literature review and a postal questionnaire survey involving 30 managers employed by International Organization for Standardization-certified construction companies. The paper concluded that functionality and customer satisfaction are two of the most important criteria for measuring the success of a construction project, while time and expense were the least important criteria for measuring construction project performance.

Öztaş et al. [17] reviewed the way in which studies and further analysis find a way to quantify the efficacy of QMS. First, a questionnaire survey was carried out on a sample of construction firms in Turkey that had or had not gone through these processes in order

to accomplish this objective. Assessing some conclusions from the results of the survey, using the most common statistical program "SPSS 10.0 for Windows", the number of QMS operating companies and their way of applying QMS concepts were calculated. In a research study, these concepts were tested by designing quality assessment matrices for QMS operating companies and various findings were concluded. In addition, Alfahham and Alajeeli [18] considered providing necessary information for owners, project managers, designers, and contractors to recognize the primary and secondary factors that have a significant effect on improving the quality of government building construction projects and minimizing maintenance. Their research also aimed to establish a predictive model for measuring the quality of these projects, and a literature review and interviews were performed. A personal figure was sent to the owners, project managers, and engineers employed on general construction projects in Iraq to collect a list of factors influencing the quality of government building projects, and the resulting factors were surveyed. Multiple linear regression methodology was adopted in the modelling process and the most important factors affecting project quality were determined.

Shokouh et al. [19] introduced a dynamic system model to research the significance and behavior of the variables that influence the construction quality of the structures of buildings. For a case study, the proposed model for their paper was evaluated and the findings discussed. To compare the effects of the proposed process, the paper also used the DEMATEL technique. The paper described all the factors that influence the construction quality of the structures of the buildings. According to Sheikh et al. [20], the quality of construction projects depends primarily on the quality of the process during the construction phase rather than the quality of the product approach. The variables were categorized using the conventional relative importance index (RII) and the second method of synthetic grey relational analysis. The results showed that the selection of a suitable contractor is the most important factor during the construction process. The study was a pioneering work in the assessment of key factors that affect the quality of processes during construction projects in Pakistan that used a set of conventional and novel methods to improve process quality during various phases of construction.

Baiburin [21] stated that aspects included in systematic evaluation are quality system-level metrics, the absence of defects, the stability of engineering procedures, and building safety indexes. Calculation formulas were provided for statistical values considering the type of parameter distribution. Index values for the two control phases were estimated using process technology accuracy regulation. Analysis of construction quality was carried out using the example of solid building construction. The impacts of different defects on the safety index for construction were studied. It also disclosed the root causes of defects. Furthermore, Huang et al. [22] first expounded on the significance of promoting the green construction of high-quality settlement buildings, then analyzed three major problems in the construction process of settlement buildings based on the data of previous research, and then proposed appropriate countermeasures and recommendations to encourage the sustainable growth of high-quality settlement buildings on this basis.

D. M. Xu et al. [14] provided the main factors affecting construction process quality control in a building construction project. This system includes preconstruction quality planning, quality control, drawings reviewing technical tests, building product quality control, responsibility for quality, and other aspects. The practical application of this system in building construction projects proved its effectiveness in project quality control. Likewise, Alawag et al. [23] stated that quality management is widely considered to be a crucial method for enhancing the output quality of organizations in the construction industry. Their study aimed to determine and prioritize the critical success factors that impact the quality management of construction projects in Malaysia. They collected questionnaire data and analyzed them statistically, finding that leadership is the most important factor. However, all contributing factors were found to have a significant influence on successful project performance. The study then developed a conceptual framework based on the top critical factors identified. Finally, most of the previous work has explained a lot about

quality building construction method and building construction performance, but none of them have talked about a quality assessment model for construction work that can improve the quality of construction in Saudi Arabia. The quality of building construction is important and cannot be neglected, and it can be improved by adding a new model based on the AHP method and criteria of quality.

In 2022, Rahif et al. [24] defined the phrase "climate change overheating resistivity" and provided a method for calculating it. In addition, the evaluation of a wide range of active and passive cooling solutions was then made possible through the introduction of a comprehensive simulation-based framework. The framework's three main indicators—interior overheating degree (IOD), ambient warmth degree (AWD), and climate change overheating resistivity (CCOR)—allowed for a multizonal approach to interior overheating risk and resistance to climate change. The performance of a variable refrigerant flow (VRF) unit combined with a dedicated outdoor air system (DOAS) (C01) and a variable air volume (VAV) system (C02) was contrasted in six different locations/climates to test the suggested framework. The case study was a shoebox model of an office structure with two zones. Generally speaking, the C01 displayed higher CCOR values than the C02 between 2.04 and 19.16 in various scenarios. Furthermore, according to Zhang et al. [25], a lifecycle assessment can be used to evaluate air emissions during construction. Therefore, their study analysed the sources of emissions at each stage of the six stages of a building's lifecycle and proposed an inventory analysis approach to evaluate air emissions. Actions can be taken early on to mitigate environmental consequences during a building's lifecycle by examining the effect of building installation on air quality. As a result, the method was used in a case study to be applied to Hong Kong construction practices for every step of the lifecycle.

The sustainability of contemporary concrete construction methods in single-family homes was evaluated by Sanchez-Garrido et al. [26]. A traditional reference design, a precast design, a lightweight slab design with pressurized hollow discs, and a design using double-wall structural parts were all compared on the basis of how sustainable they are. Thirty-eight indicators that considered the designs' social, economic, and environmental implications as well as their effects on the environment were used to evaluate their sustainability. The five most well-known multicriteria decision making (MCDM) approaches (SAW, COPRAS, TOPSIS, VIKOR, and MIVES) were used to calculate the lifecycle performance of each design. In addition, a global structural sustainability index (GSSI) incorporating and weighing the aforementioned was necessary because there was no agreement on which MCDM technique performs best in sustainability assessments.

3. Methodology

This section discusses the methodology and its components. This work was used to develop a quality assessment model for evaluating the building construction in Saudi Arabia. The first phase was data collation by questionnaire and interview. Second phase started with AHP processing rate for the degree of construction activity ranging 1–9. The first step was to make the comparison matrix, second was pairwise comparison, third normalization, and forth calculating the consistency ratio. The fifth phase was calculating all construction activity using the AHP method. The sixth phase was measuring the quality for each activity. The seventh phase was a case study to test the model. The final phase was quality model assessment for evaluating building constriction in Saudi Arabia as shown in Figures 1 and 3.

The research methodology presented in Figures 3 and 4 is divided into three parts as the following:

1. Identify the main criteria that measure the level of quality of the building's construction;
2. Improve the quality of building construction projects in Saudi Arabia using a proper quality assessment model;
3. Calculate the degree of difficulty in quality implementation of each activity by using the analytic hierarchy process (AHP);

4. Develop the new model quality assessment model for evaluation of building construction in Saudi Arabia to measure quality;
5. Develop the final model and test it on a real building.

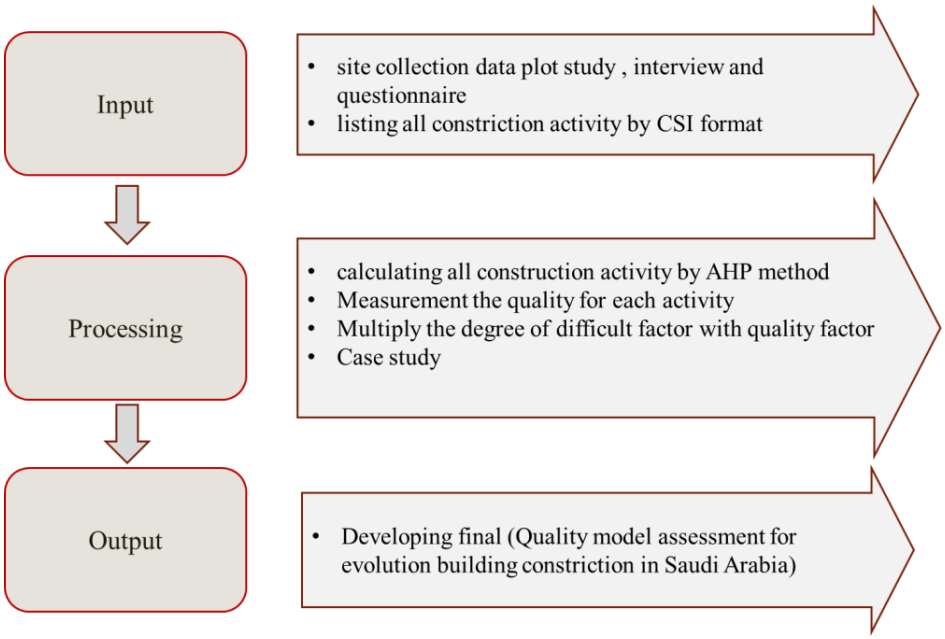


Figure 3. Methodology framework.

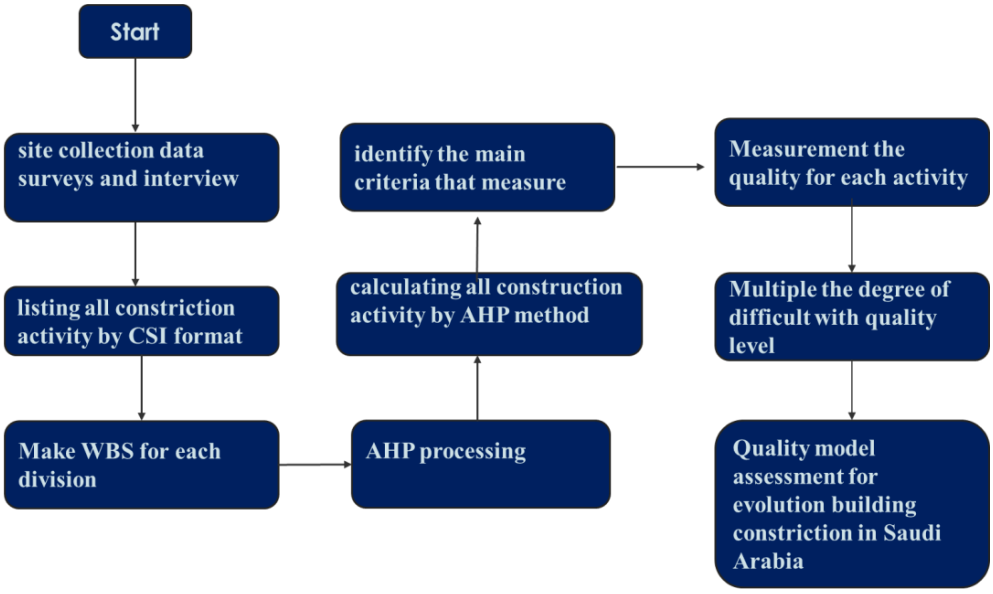


Figure 4. Flowchart of the proposed model.

4. Data Collection and Findings

4.1. Interview and Survey

This research conducted interviews with a contractor and quality manager for building construction. Moreover, some engineers in a work site that was under construction took the interview. They were asked about how to measure the quality of construction building and ask the contractor about the construction activity for a commercial building. After interviewing the contractor, some information about construction activity was gathered, consisting of 16 divisions by CSI format, as shown in Figure 2.

In Figure 5, each section has several divisions and activities.

Division	#	Activity list
SITE CONSTRUCTION 0.2	1	Excavation and leveling (Sand Soil) Raft
	2	Excavation and leveling (Sand Soil)
	3	Excavation and leveling (Clay Soil)
	4	Excavation and leveling (Ordinary Rock) 5
	5	Excavation and leveling (Hard Rock)
	6	Backfilling & Compaction - isolated footings
	7	Backfilling & Compaction - Raft & Roads 8
	8	Backfilling & Compaction - under grade slab
	9	Site Surveying & Excavation/ Backfiling Works
	10	Soft & Hard Scaping
CONCRETE WORK 0.3	11	Plain Concrete under foundation (Shutteing) — Isolated
	12	Plain Concrete under foundation (pouring) — Isolated
	13	Plain Concrete under foundation (pouring) — Raft
	14	Plain Concrete under foundation(Shuttering) —Raft
	15	Form work for foundation (Raft type)
	16	Form work for foundation (Isolated type)
	17	steelwork for foundation (Raft type)
	18	steel work for foundation (Isolated type)
	19	pouring for foundation (Raft type)
	20	pouring for foundation (Isolated type)
	21	Form work for Grade Beams (Shuttering)
	22	steel work for Grade Beams
	23	Grade Beams (pouring)
	24	Form work for column necks (Shuttering)
	25	steel work for column necks
	26	Column necks (Pouring)
	27	Form work for Slab on grade (S.O,G)
	28	steel work for Slab on grade (S.O.G)
	29	pouring for Slab on grade (S.O.G)
	30	Shuttering for Column and Stair
	31	Shuttering for Slab and Beams
	32	Steel Fixing for Column and stair
	33	Steel Fixing for Slab and Beams
	34	Pouring for Column and Stair
	35	Pouring for Slab and Beams
	36	upstend for wall
	37	installattion of hollow core slab. Stirs and grouting
	38	38Installation of Precast Wall Panels
	39	Installation of Precast Elements for Pergola
	40	installattion of precast perimete fance and gate
MASONRY 0.4	41	Masonry Work for internal wall 200 mm
	42	Masonry Work for internal wall 150 mm
	43	Masonry Work for internal wall 100 mm
METALS 0.5	44	Installation of the Roof Steel Structure Framing
	45	Handrail at internal stairs
	46	Stainless eel handrail, atextern -handi
WOOD AN PLASTICS 0.6	47	Installation of Kitchen Cabinets
	48	Pergola Works
	49	Non Movable Furniture (Closet, Wardrobe and Shelves)
	50	Install internal wooden column encasements
	51	Install wood skirting and trim including finishing
THERMAL MOSTURE PROTECTION 0.7	52	tow coats of bituminous paint for foundation (brshing)
	53	Two coats of Bituminous paint for foundation (Membrane sheets)
	54	Termite protection & Polyethylene sheet
	55	Wet Area Water Proofing
	56	Expansion Joints Filling
	57	install roof water profing system

Figure 5. *Cont.*

FINSHES 0.9	64	plaster work for celling and wall
	65	Ceramic/ Porcelain tiles for wall
	66	Ceramic / porcelain tiles for floor Flooring
	67	Marble for stair & entrance
	68	Stair riser finishing (Skirting)
	69	Skirting For Ceramic / porcelain
	70	Granite Tiles For Steps Treads, Rises
	71	Painting Surface preparation
	72	Internal painting 1st coat
	73	Internal painting 2nd coat
	74	Epoxy paint
	75	1st stahe gypsum board celling
	76	1st Stage Gypsum Board Ceiling
	77	Final Stage Gypsum Board Ceiling
	78	Gypsum Board Ceiling
	79	Ceiling Cornic Moulding
	80	Granite or Marble for wall (not mechanical)
	81	Granite or Marble for wall (mechanical)
	82	Decorative Columns (GRC)
	83	GRC Decoration
	84	Gypsum Board Cladding
	85	Vinyl
	86	External Plaster for Walls
	87	External Painting Surface preparation
	88	External painting 1st coat
	89	External painting 2nd coat
	90	Roofing Finishes (Wooden batten, Ply wood, Terra kot)
	91	Screed Laying
	92	Hand Rail GypsumFraming and Gypsum Board Installation, Wood
specialties 0.9	93	install prefabricated toilet partitions
	94	install bathroom accessories and fittings
	95	installation Shelving Storage
	96	installation Wall and Corner Guards
equipment 11	97	parking control equipment
	98	office equipment
	99	Observatory Equipment
	100	unit kitchens
furnishings 12	101	install Furnishings and Accessories
	102	install Interior Plants
	103	install fabrics and curtains
special construction13	104	Swimming pool works
	105	Aquariums works

Figure 5. *Cont.*

convrying systems 14	106	Passenger Elevator
mechanical 15	107	fire fighting pipes line
	108	fire water sprinkler
	109	HVAC air outlets and accessories
	110	HVAC Ducting , Piping and insulation
	111	Install Fire Extinguishers
	112	Installation of Electric water heater
	113	Pre-cast Concrete Scupper
	114	Installation of Exhaust Fans
	115	Installation of bathtubs
	116	Installation of Recirculating hot water pump
	117	Installation split AC Units(AHU, ACCU)
	118	Plumping, Irrigation & HVAC Works (roof/oustsite)
	119	Drainage Roof System
	120	U/G utility for mech. and elect.
	121	Water & Waste Pipes
	122	Installation of Gate Valve, Balancing Valve, Check Valve & Mixing Valve & Hose BIB
	123	Installation of Spilt units & Accessories
	124	Installation of Spilt units on roof
	125	Laying of Hot& Cold Water Pipes - concealed
	126	laying of hot a cold water pipes - surface
Electriacal	127	Cabinets Termination and Splicing
	128	Cable pulling 'DATA /VOICE/IPTVANDSMATVSYSTEM
	129	Electrical & Communication Works
	130	Electrical & Telecommunication Rough in
	131	Electrical Wirings
	132	Installation of Cabinets & Accessories-G.F
	133	MEP FINAL FIXTURES & DEVICES
	134	panel Board Fixation
	135	Panel Board Termination
	136	MEP Testing & Commissioning for the Villa
	137	Installing Cable Tray
	138	Joint electrical conduits between floor and walls
	139	Joint electrical conduits for floor
	140	Joint electrical conduits for walls
	141	Fire Alarm electrical conduits
	142	Fire Alarm Cabling
	143	Fixing of Access for Fire Detection System (Heat Detectors,...)
	144	Fixing of Accessories for TELECOM and data system
	145	Fixing of Access for Fire Detection System

Figure 5. Division and activities list.

4.2. Work Breakdown Structure (WBS)

After finishing the construction activity list, a work breakdown structure (WBS) was developed for each division, as shown in Figure 6.

4.3. Questionnaire

The questionnaire part of this study required filling the pairwise matrix by asking experts about the degree of difficulty in applying quality in construction activity. The purpose of the questionnaire is to identify the affected elements of the quality model. The questionnaire was sent to 90 Saudi experts in the field of construction management. Out of the 90 experts, 31 filled the questionnaire. Twenty-four respondents had more than 10 years of experience, while 7 had less than 5 years of experience. Ultimately, the questionnaire answers of 28 respondents were selected. The questionnaire data were investigated using AHP theory; this variation resulted in different weights for the selected assessment attributes (Figure 7). Consequently, these weights deliver a context for the quality of construction management and account for variations in values. In addition, the questionnaire is the part of a study to fill the pairwise matrix by asking experts about the degree of difficulty in applying quality to construction activity. An example of the questionnaire is shown in Figure 7.

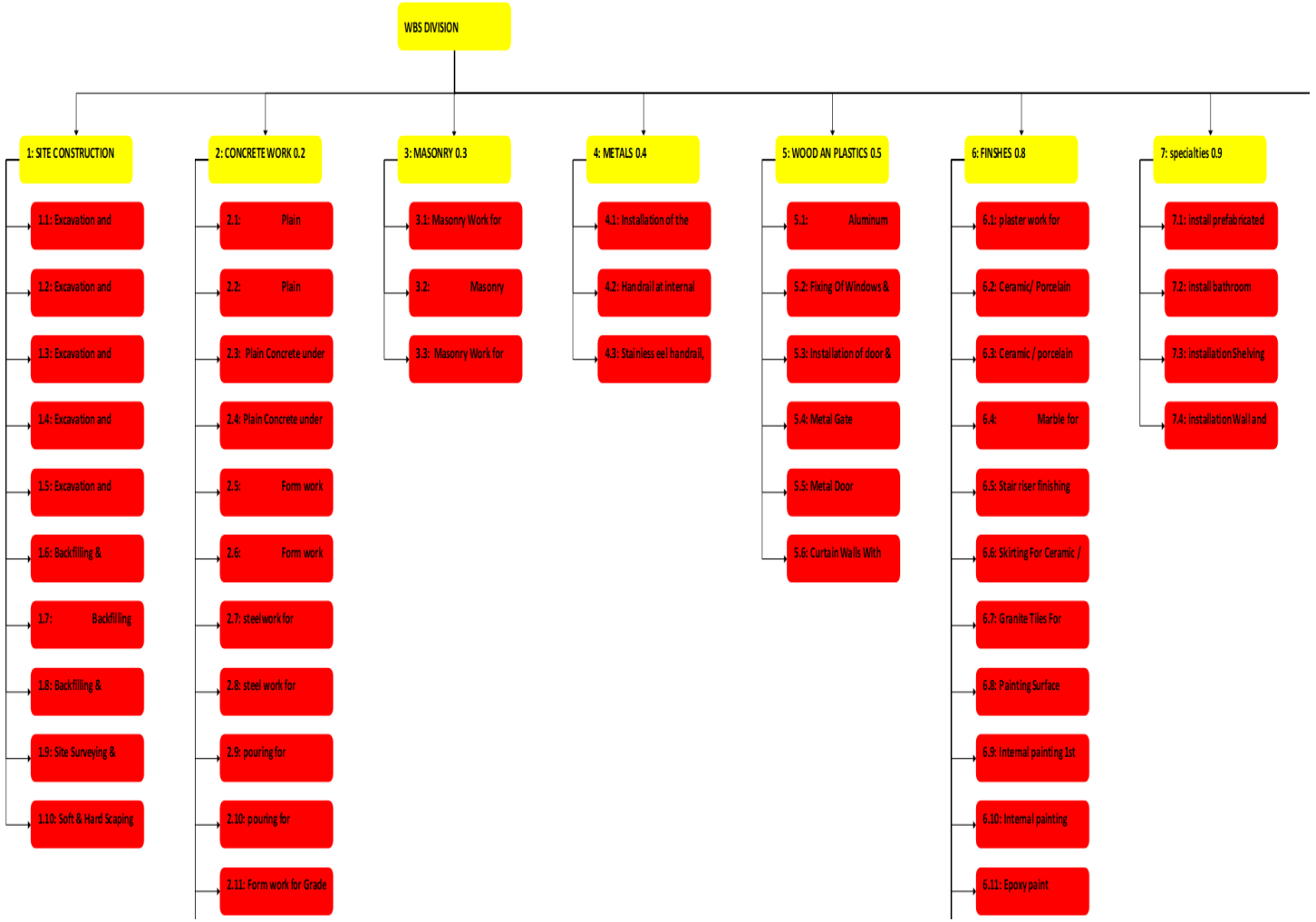


Figure 6. Work breakdown structure (WBS) sheet.

وزارة التعليم
Ministry of education

المملكة العربيه السعوديه
Kingdom Saudi Arabia

جامعة الإمام عبد الرحمن بن فيصل
IMAM ABDULRAHMAN BIN FAISAL UNIVERSITY

College of Architecture and Planning

QUALITY ASSESSMENT MODEL FOR EVALUATION OF BULIDING CONSTRUCTION IN SAUDI ARABIA

This questionnaire is part of a study for evaluations the **quality level index** for each activity related to the commercial project in Saudi Arabia based on 16 division. It would help the stockholders to calculate the actual progress on site, based on work performed of using the quality rate.

quality level index: construction project may be delayed due to lack of understanding and lack of applying the quality found in the project. one of the reasons for construction projects Daley was due to a lack of applying and considering the quality during construction stage for commercial project on Saudi Arabia.

your judgment and experience in filling the pairwise comparison in this questionnaire beside the expert- knowledge collected will be the basis in identifying the quality rate for construction each activity in the16 division that will contribute to the quality assessment model for commercial project in Saudi Arabia.

Finally, we would like to thank you for your kind cooperation.

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(**a**)

General information (optional)

1- Participant information

Name.....

Position.....

Name of institution.....

Mobile no .....

E-mail.....

2- How many years of experience you have?

.....

3 -Have you ever worked on quality in construction?

.....

4-Project on which you have most experience can be categorized as?

.....

(**b**)

Figure 7. *Cont*.

Pair wise comparison

This table illustrates a measure of the difficulty of implementing quality in the construction activities.

scale	degree of difficulty
9	extrmely difficult
8	very strongly to extremely
7	very strongly difficult
6	strongly to very strongly
5	strongly difficulty
4	moderately to strongly difficult
3	moderately difficulty
2	equally to moderately
1	Equally difficult

Measured on an integer- valued 1-9 scale as mentioned above (1) table

SITE CONSTRUCTION 0.2
QUALITY ASSESSMENT MODEL FOR EVALUATION OF BULIDING CONSTRUCTION IN SAUDI ARABIA
degree of difficulty

activity	extmely difficulty(9)	very strongly to extmely (8)	very strongly difficulty(7)	strongly to very strongly (6)	strongly difficulty(5)	moderately to strongly difficulty(4)	moderately difficulty(3)	equally to moderately (2)	Equally difficulty (1)	equally to moderately (2)	moderately difficulty (3)	moderately to strongly difficulty(4)	strongly difficulty(5)	strongly to very strongly (6)	very strongly difficulty(7)	very strongly to extmely (8)	extmely difficulty(9)	activity
0) Raft (D)																		Excavation and leveling (A) (Sand Soil)
																		Excavation and leveling (B) (Clay Soil)
																		Excavation and leveling (C) (Ordinary Rock) 5

this example shows how the questionnaire work:

1- D is extremely difficult applying the quality more than A
2- B is very strongly difficult applying the quality more than D
3- C is equally difficult D

(**c**)

MASTER FORMAT 0.1
QUALITY ASSESSMENT MODEL FOR EVALUATION OF BULIDING CONSTRUCTION IN SAUDI ARABIA
degree of difficulty

activity	extmely difficulty(9)	very strongly to extmely (8)	very strongly difficulty(7)	strongly to very strongly (6)	strongly difficulty(5)	moderately to strongly difficulty(4)	moderately difficulty (3)	equally to moderately (2)	Equally difficulty (1)	equally to moderately (2)	moderately difficulty (3)	moderately to strongly difficulty(4)	strongly difficulty(5)	strongly to very strongly (6)	very strongly difficulty(7)	very strongly to extmely (8)	extmely difficulty(9)	activity
SITE CONSTRUCTION 0.2																		CONCRETE WORK 0.3
																		MASONRY 0.4
																		METALS 0.5
																		WOOD AN PLASTICS 0.6
																		THERMAL MOSTURE PROTECTIC
																		DOOR WINDOWS 0.8
																		FINSHES 0.9
																		SECIALTES 10
																		equipment 11
																		furnishings 12
																		special construction 13
																		convrying systems 14
																		mechanical 15
																		Electriacal 16

SITE CONSTRUCTION 0.2
QUALITY ASSESSMENT MODEL FOR EVALUATION OF BULIDING CONSTRUCTION IN SAUDI ARABIA
degree of difficulty

activity	extmely difficulty(9)	very strongly to extmely (8)	very strongly difficulty(7)	strongly to very strongly (6)	strongly difficulty(5)	moderately to strongly difficulty(4)	moderately difficulty (3)	equally to moderately (2)	Equally difficulty (1)	equally to moderately (2)	moderately difficulty (3)	moderately to strongly difficulty(4)	strongly difficulty(5)	strongly to very strongly (6)	very strongly difficulty(7)	very strongly to extmely (8)	extmely difficulty(9)	activity
Excavation and leveling (Sand Soil) Raft																		Excavation and leveling (Sand Soil)
																		Excavation and leveling (Clay Soil)
																		Excavation and leveling (Ordinary Rock) 5
																		Excavation and leveling (Hard Rock)
																		Backfilling & Compaction - isolated footings
																		Backfilling & Compaction - Raft & Roads 8
																		Backfilling & Compaction - under grade slab
																		Site Surveying & Excavation-Backfilling Works
																		Soft & Hard Scaping

(**d**)

Figure 7. Sample of questionnaire sheet (**a**–**d**).

Furthermore, it was difficult from the beginning to determine the appropriate sample size required to develop the framework due to the lack of available information on the actual number of experts in quality management and engineering of construction projects in the conducted research region. However, the authors were concerned about some factors that governed the sample size including response rate (30%), completeness of the whole parts of survey (17 matrix), consistency, and reliability test (<0.1). Hence, 90 paper-based surveys were administered to managers and engineers working in quality assurance in construction contracting companies in the region. These surveys were administered using face-to-face meetings in order to explain the survey as well as to achieve a good response rate (>30%). A study carried out by Shih and Xitao (2008) analyzed a total of 39 different studies that applied the data collection tool administered by paper and online. The results show that the average response rate of the web survey was 33.87% while the paper-based response rate was 44.56%. In the conducted study, 31 out of 90 responses were received, which represents 34.4% of the total administrated survey. Three out of 31 received responses were eliminated due to incomplete response. Since the AHP is considered a smart technique that can be filled carefully by a limited number of experts, it does not require a high quantity of response, but rather high quality of information. The quality of responses was assured in this study by measuring the reliability and consistency of response (CI and CR). In this study, 16 responses were found to have some issues in their consistency rate with CI and CR values more than 0.1. The authors decided to exclude them to obtain more reliable and consistent results. Finally, 12 responses were considered acceptable and found to be reliable and achieve high level of consistency, with CI and CR values less than 0.1. Two previous studies applying the AHP technique had an almost similar average number of utilized responses at 13 and 15 responses [27,28] (Alshamrani 2012; Alshamrani et al., 2018). In addition, a strong safety culture helps create a safe workplace, according to Umar and Egbu [29]. The idea of safety climate was examined in their essay. It identified some of the key factors that significantly affect Oman's building industry. Using precise search criteria, relevant safety and climate aspects were found in the literature, resulting in 62 factors, spanning a period of 37 years.

4.4. AHP Processing

For each questionnaire filled, the pairwise matrix process for data in this analysis consisted first of the AHP questionnaire and second of the filling of the pairwise matrix. Third was normalization, fourth was consistency ratio to check each questionnaire—if the consistency was over 0.1 it was rejected; if less than 0.1 it was accepted—finally developing the degree of difficulty in applying quality, as shown in Figure 8.

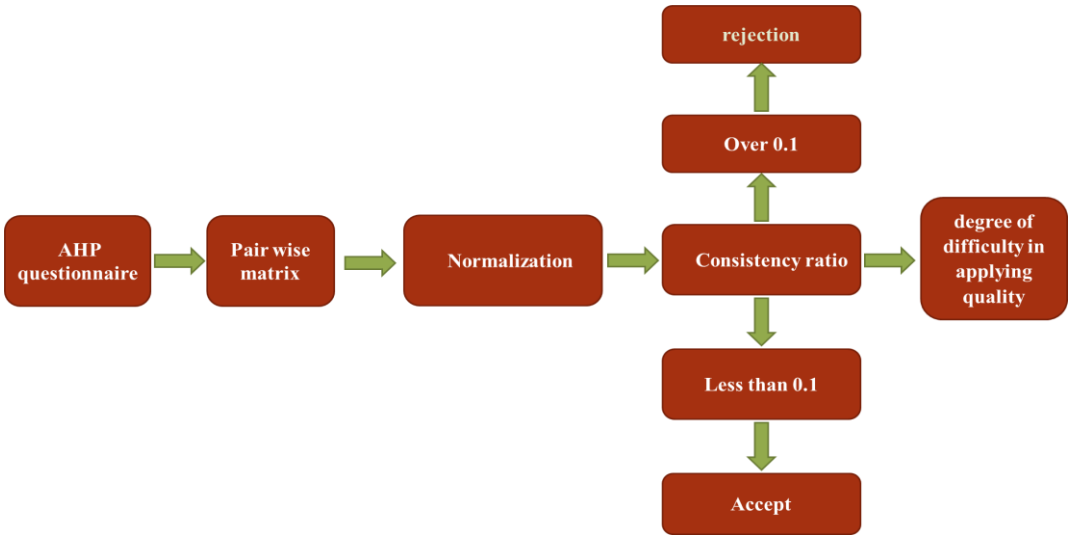


Figure 8. Data analysis flowchart.

5. Model Implementation

Data were collated from the interviews and questionnaires asking the expert engineers about the degree of difficulty for applying quality. The model contains 16 divisions (master format, concrete work, etc.), and this section discusses data analysis using the analytical hierarchy process (AHP) by firstly making a comparison matrix [30]. Then, pairwise comparison and normalization are conducted. Finally, a consistency ratio to check the accuracy of the data is applied. The construction activity data are adjusted accordingly for a natural construction project for a commercial building. After finishing the (AHP) process, a case study is used to check the efficiency of the model and measure the quality of building construction.

5.1. Data Analysis

5.1.1. Pairwise Matrix

The weights of the objects in the column are the most important target of a couple of comparisons. The criteria in the rows are compared to the criteria in the columns, with each segment having an equal comparison. The decision-maker must also compare all tasks at the same level in terms of the difficulty weights correlated with their expertise and experience, as shown in Figure 9.

site constraction													
Number of Factors	Number of Factors	1	2	3	4	5	6	7	8	9	10	TOTAL	Avg.
Number of Factors	site constraction	Excavation and leveling (Sand Soil) Raft (D)	Excavation and leveling (A) (Sand Soil)	Excavation and leveling (B) (Clay Soil)	Excavation and leveling (C) (Ordinary Rock) 5	Excavation and leveling (Hard Rock)	Backfilling & Compaction - isolated footings	Backfilling & Compaction - Raft & Roads 8	Backfilling & Compaction - under grade slab	Site Surveying & Excavation-Backfiling Works	Soft & Hard Scaping		
1	Excavation and leveling (Sand Soil) Raft (D)	1.00	0.25	0.25	0.25	0.25	3.00	3.00	3.00	1.00	1.00	13.00	1.30
2	Excavation and leveling (A) (Sand Soil)	4.00	1.00	1.00	1.00	1.00	12.00	12.00	12.00	4.00	4.00	52.00	5.20
3	Excavation and leveling (B) (Clay Soil)	4.00	1.00	1.00	1.00	1.00	12.00	12.00	12.00	4.00	4.00	52.00	5.20
4	Excavation and leveling (C) (Ordinary Rock) 5	4.00	1.00	1.00	1.00	1.00	12.00	12.00	12.00	4.00	4.00	52.00	5.20
5	Excavation and leveling (Hard Rock)	4.00	1.00	1.00	1.00	1.00	12.00	12.00	12.00	4.00	4.00	52.00	5.20
6	Backfilling & Compaction - isolated footings	0.33	0.08	0.08	0.08	0.08	1.00	1.00	1.00	0.33	0.33	4.33	0.43
7	Backfilling & Compaction - Raft & Roads 8	0.33	0.08	0.08	0.08	0.08	1.00	1.00	1.00	0.33	0.33	4.33	0.43
8	Backfilling & Compaction - under grade slab	0.33	0.08	0.08	0.08	0.08	1.00	1.00	1.00	0.33	0.33	4.33	0.43
9	Site Surveying & Excavation-Backfiling Works	1.00	0.25	0.25	0.25	0.25	3.00	3.00	3.00	1.00	1.00	13.00	1.30
10	Soft & Hard Scaping	1.00	0.25	0.25	0.25	0.25	3.00	3.00	3.00	1.00	1.00	13.00	1.30
TOTAL		20.00	5.00	5.00	5.00	5.00	60.00	60.00	60.00	20.00	20.00		

Figure 9. Division and activities weights.

5.1.2. Normalization

Normalization was used to obtain matrix normalization by summing the total numbers within each column, as each entry in the column is also divided using the column sum to obtain all the measured points, and the sum of each column is 1 [14], as shown in Figure 10.

master format																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total	Average
1	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.035	0.031	0.031	0.473	0.032
2	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.069	0.063	0.063	0.946	0.063
3	0.157	0.157	0.157	0.157	0.157	0.157	0.157	0.157	0.157	0.157	0.157	0.157	0.173	0.157	0.157	2.365	0.158
4	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.017	0.016	0.016	0.237	0.016
5	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.079	0.005
6	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.021	0.019	0.019	0.282	0.019
7	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.058	0.052	0.052	0.788	0.053
8	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.035	0.031	0.031	0.473	0.032
9	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.035	0.031	0.031	0.473	0.032
10	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.138	0.125	0.125	1.892	0.126
11	0.157	0.157	0.157	0.157	0.157	0.157	0.157	0.157	0.157	0.157	0.157	0.157	0.173	0.157	0.157	2.365	0.158
12	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.035	0.031	0.031	0.473	0.032
13	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.035	0.031	0.031	0.473	0.032
14	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.035	0.125	0.125	1.788	0.119
15	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.138	0.125	0.125	1.892	0.126
																	1.00

Figure 10. Normalization of division 1.

5.1.3. Consistency Ratio

The verification and percentage of consistency calculations are an operation on the original preferences and rankings, with the goal of verifying the decision-maker's judgement obtained by comparing pairs. or pairwise comparisons, the CR value should be 0.1 or less for acceptable consistency. A ratio value of more than 0.1 indicates that the decision is inconsistent, and the findings are not very accurate [17], as shown in Figure 11.

No	Activities	Geometric Mean	EV Wieght	Aω	λ	CI	CR
1	SITE CONSTRUCTION 0.2	0.68936258	0.032	0.471	14.9		
2	CONCRETE WORK 0.3	1.37872516	0.063	0.943	14.9		
3	MASONRY 0.4	3.4468129	0.158	2.357	14.9		
4	METALS 0.5	0.34468129	0.016	0.236	14.9		
5	WOOD AN PLASTICS 0.6	0.114893763	0.005	0.079	14.9		
6	THERMAL MOSTURE PROTECTION 0.7	0.411068921	0.019	0.281	14.9		
7	DOOR WINDOWS 0.8	1.148937633	0.053	0.786	14.9		
8	FINSHES 0.9	0.68936258	0.032	0.471	14.9		
9	SECIALTES 10	0.68936258	0.032	0.471	14.9		
10	equipment 11	2.75745032	0.127	1.885	14.9		
11	furnishings 12	3.4468129	0.158	2.357	14.9		
12	special construction 13	0.68936258	0.032	0.471	14.9		
13	convrying systems 14	0.68936258	0.032	0.471	14.9		
14	mechanical 15	2.514029468	0.115	1.791	15.0		
15	Electriacal 16	2.75745032	0.127	1.885	14.9		
Total		21.76767558	1.00		14.9	0.00	0.00

Figure 11. Weight of division CR.

The degree of difficulty in applying quality division 15, the degree of difficulty in applying quality division 13, "firefighting pipes line" 3%, "fire water sprinkle" 5%, "HVAC air outlets and accessories" 7%, "HVAC Ducting, Piping and insulation" 2%, "Install Fire Extinguishers" 8%, "Installation of Electric water heater" 3%, "Pre-cast Concrete Scupper" 6%, "Installation of Exhaust Fans" 4%, "Installation of bathtubs" 6%, "Installation of Recirculating hot water pump" 4%, "Installation split AC Units (AHU, ACCU)" 4%, "Plumping, Irrigation and HVAC Works (roof/oust site)" 6%, "Drainage Roof System" 5%, "U/G utility for mech. and elect" 7%, "Water and waste pipes" 7%, "Installation of Gate Valve, Balancing Valve, Check Valve and Mixing Valve and Hose BIB" 5%, "Installation of Spilt units and Accessories" 3%, "Installation of Spilt units on roof" 5%, "Laying of Hot and Cold Water Pipes—concealed" 5%, "laying of hot and cold-water pipes—surface" 4%, as shown in Figure 12.

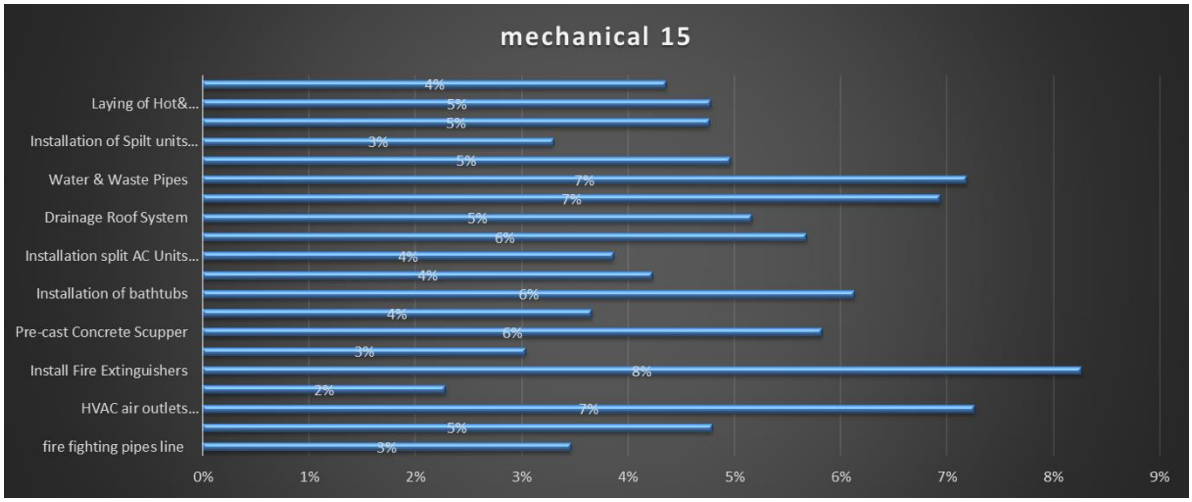


Figure 12. Degree of difficulty division 15.

The degree of difficulty in applying quality division 16, "Cabinet Termination and Splicing" 4%, "Cable pulling 'DATA/VOICE/IPTVANDSMATVSYSTEM'" 5%, "Electrical and Communication Works" 5%, "Electrical and Telecommunication Rough" 2%, "Electrical Wirings" 5%, "Installation of Cabinets and Accessories-G.F" 4%, "MEP FINAL FIXTURES and DEVICES" 4%, "panel Board Fixation" 6%, "Panel Board Termination" 6%, "MEP Testing and Commissioning for the Villa" 7%, "Installing Cable Tray" 2%, "Joint electrical conduits between floor and walls" 8%, "Joint electrical conduits for floor" 7%, "Joint electrical conduits for walls" 8%, "Fire Alarm electrical conduits" 7%, "Fire Alarm Cabling" 7%, "Fixing of Access for Fire Detection System (Heat Detectors,...)" 5%, "Fixing of Accessories for TELECOM and data system" 4%", "Fixing of Access For Fire Detection System" 6%, as shown in Figure 13.

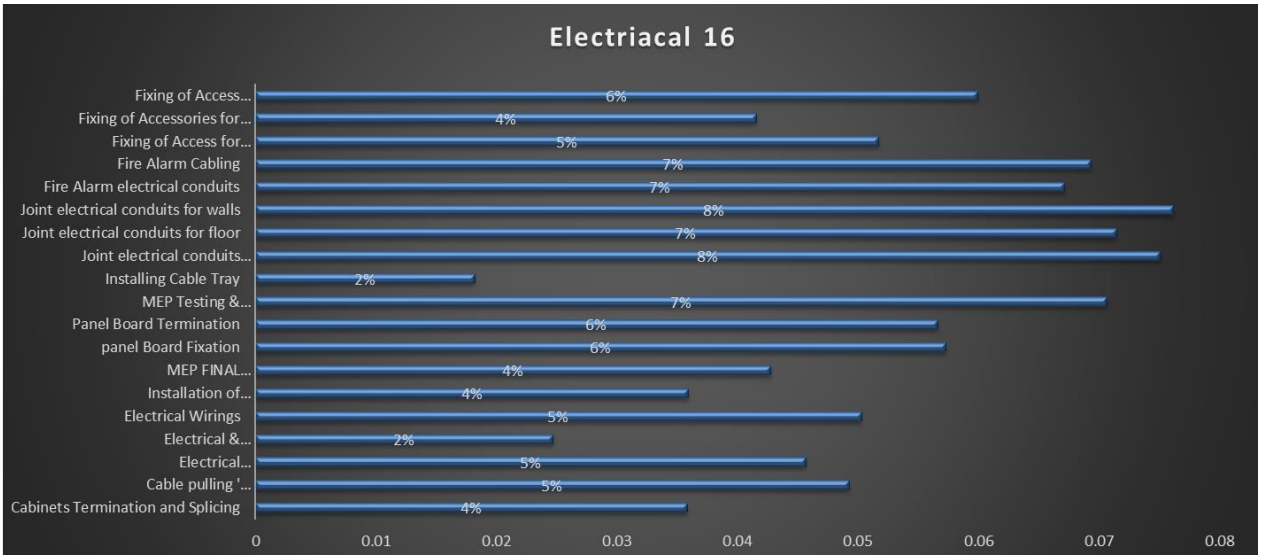


Figure 13. Degree of difficulty division for electricity.

5.2. Final Quality Model

The final model starts with the AHP questionnaire, and is followed by the filling of the pairwise matrix. The third step is normalization, fourth consistency ratio to check each questionnaire for if the consistency is over 0.1, resulting in rejection, or less than 0.1, resulting in acceptance of the questionnaire. The final step consists of developing the degree of difficulty in applying quality; the quality equation is (quality level measurement × degree of difficulty in

applying quality using AHP/perfect factor = total quality of building), where 100–80% = very good, 80–70% = good, 70–60% = acceptable, 60–0% = poor.

6. Results and Discussion

Interviews and questionnaires were used to gather information, and professional engineers were asked to rate how challenging it was to apply quality. For 16 divisions (master format, concrete work, etc.), a comparison matrix was created using analytical hierarchy processing (AHP). Pairwise comparisons and normalization were performed on the data. The consistency ratio was calculated to make sure the data were correct. The data were modified to account for construction activity for a commercial building using a natural construction project as a model. Following the (AHP) process, the case study assessed the model's effectiveness and quality. *Applying the quality model in three different case's*:

Quality equation = degree of difficult in applying quality × quality level = total quality, as shown in Figure 14.

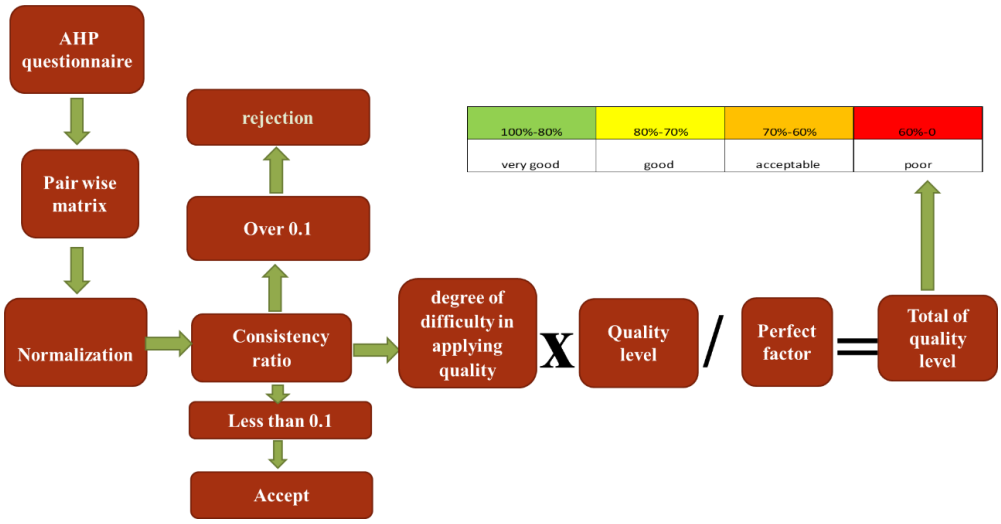


Figure 14. Quality model stages.

Quality Level for all Cases

The conclusion for all cases is that the total quality in case 1 is 92%, and is only good in site construction and concrete work, because skeleton work is very import for building construction. The total quality in case 2 is 86%, and is good only in site construction, concrete work, finishes, and mechanical work. The total quality in case 3 is 72%, and is good in all project activities, as shown in Figure 15.

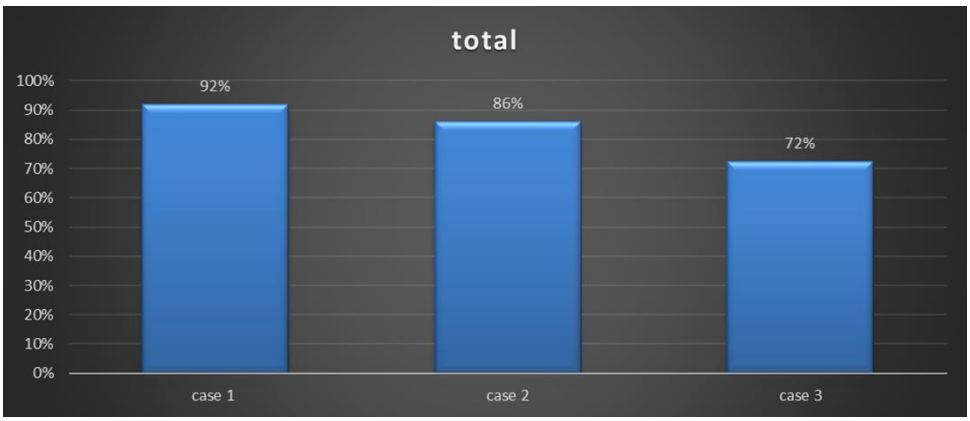


Figure 15. Quality level for all case studies.

7. Conclusions

This research paper developed a framework for assessing building construction quality in Saudi Arabia. The framework was developed based on a comprehensive literature review, expert interviews, and a pilot study conducted in Saudi Arabia. It also determined the degree of difficulty in implementing quality for each construction activity by using AHP. It was extremely difficult to apply quality to finishing work with a 12% degree of difficulty since it required more time and equipment. Since the material has already been prepared, 4% of the difficulty of applying quality in metal working can be considered very low. This demonstrates the effectiveness of the quality model. Overall, the quality of case 2 was 86% acceptable, except for construction on the site, concrete work, finishes, and mechanical work. Case 1 had a total quality of 92%, which is good, only in site construction and concrete work, while case 3 had a total quality of 72%, which is good for all activities of the project. The results of this research will be helpful to architects, engineers, quality specialists, and other people involved in Saudi Arabian construction. The tool will enable them to make informed decisions regarding the quality of construction. Future research recommendations include suggesting more questionnaire surveys to enhance reliability of the results and improve the generalizability of the findings.

For future work, the following suggested points should be considered:

- More experts can be asked about quality to obtain more information on the issue of quality in construction.
- The number of respondents can be increased to obtain more accurate information.
- Another model can be made to measure the quality of construction work for residential buildings.
- Another model can be made to measure the quality of indoor the buildings.
- Another technique can be used to measure the degree of difficulty.

Author Contributions: G.A., A.A., O.A. and A.A.-S. developed the methodology and concept. A.A.-S. and G.A. aided in developing the methodology and concept. G.A., A.A., O.A. and A.A.-S. analyzed the findings and the results of the models and aided in writing the article. O.A. supervised this study. All authors have read and agreed to the published version of the manuscript.

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