Decision Support System for Consultant Evaluation and Ranking using Qualifications-Based Selection and Fuzzy TOPSIS Approach

by

Maram Nomir

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

in

Construction Engineering and Management

Department of Civil and Environmental Engineering
University of Alberta

Abstract

Consultant evaluation and selection is a subjective process due to the qualitative nature of evaluation criteria. A thorough evaluation that includes all the necessary criteria should be conducted. A suitable procurement method for determining proficient consultants was found to be Qualifications-Based Selection, which means that the price criterion is not considered. Owners often use both price and non-price criteria in the evaluation process. However, when price is one of the deciding factors, non-price criteria suffer because clients do not pay as much attention to consultant qualifications as they should and instead focus on the price. They may give all consultants the same rating for the qualifications-related criteria, and then the bid price determines which firm gets the job.

The objective of this research is to develop an automated decision support system to assist clients in selecting competent consultants with minimal subjectivity and improved consistency. Through a study of industry practices and an extensive literature review, this research identifies all criteria needed to properly evaluate consultants. The statistical analysis of the documents used by clients to evaluate consultants yielded the weights of the main criteria categories, which are (1) technical and (2) managerial and organizational. For this multi-criteria decision-making problem, fuzzy TOPSIS was determined to be the most appropriate technique. Fuzzy logic, which is a subset of artificial intelligence, deals with linguistic variables, whereas TOPSIS performs mathematical operations and ranks consultants. The analytical consultant evaluation and ranking model was created using the Python programming language, which is widely used for data analysis and machine learning.

The contributions of this research include the development of pre-evaluation inquiries for screening and shortlisting consultants before the detailed evaluation process to save the decision-maker time and effort by focusing on eligible consultants only. It also involves the identification of evaluation rules for measuring criteria, which will be checked by the decision-maker to objectively determine the rating for each criterion. By that, subjectivity is minimized, while transparency and fairness are reinforced, because, unlike traditional approaches, where the decision-maker is required to set the linguistic ratings, evaluation rules decide on these ratings. Furthermore, the developed analytical model is comprehensive with all the relevant criteria, including environmental considerations, sustainability, and innovation which have recently gained attention. The decision-maker has the choice of using the system's recommended criteria weights or entering different weights based on the project characteristics. The computerized system is flexible and adaptable, allowing the decision-maker to exclude any non-applicable evaluation rules that may not fit in some projects without affecting the model calculations.

Acknowledgements

I would like to express my gratitude to my supervisor Dr. Ahmed Hammad for his guidance and support throughout this research. I would also like to thank Dr. Simaan AbouRizk, the principal investigator of this project, as well as the Consulting Engineers of Alberta (CEA) and NSERC for funding it. I am grateful to our industry partners, CEA, for providing the required data and for their assistance and valuable feedback.

My sincere thanks are extended to Ms. Maria Al-Hussein, our industry liaison, and her team for their help with the Python model development.

I am also very appreciative of all the support I had from my friends. Thank you for always being there for me.

Finally, there are no words to express how blessed and grateful I am for my family. Thank you for your endless love, care, and encouragement.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AHP	Analytical Hierarchy Process
ANP	Analytic Network Process
BIM	Building Information Modeling
CBA	Choosing By Advantages
DB	Design-Build
ELECTRE	Elimination Et Choix Traduisant la REalite – ELimination and Choice Expressing the Reality
EVA	Earned Value Analysis
EMS	Environment Management System
FAHP	Fuzzy Analytical Hierarchy Process
FNIS	Fuzzy Negative Ideal Solution
FPIS	Fuzzy Positive Ideal Solution
GSCM	Green Supply Chain Management
KPI	Key Performance Indicator
MADM	Multi-Attribute Decision-Making
MAVT	Multi-Attribute Value Technique
MCDM	Multi-Criteria Decision-Making
MODM	Multi-Objective Decision-Making
NRFP	Negotiated Request for Proposal
PMBOK Guide	A Guide to the Project Management Body of Knowledge
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation

QA/QC	Quality Assurance/Quality Control
QBS	Qualifications-Based Selection
QIM	Quality Inspection and Management
RFP	Request for Proposal
RFSO	Request for Standing Offer
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
TQM	Total Quality Management
VPM	Vendor Performance Management

Chapter 1: Introduction

1.1 Background

Different procurement methods can be used in the evaluation and selection of consultants. The three most common methods are competitive bidding, qualifications-based selection (QBS), and best value procurement. Most clients, especially public ones, prefer basing their selection on the price criterion although the firm with the lowest price may not be the most qualified (Kasma, 1987).

Clients may believe that price-based procurement will save them money. On the contrary, if QBS is utilized to select consultants, it may save them money. That is because a higher design cost can result in savings during construction, which can be achieved, for example, through the consultant's consideration of sustainable low-impact design. As a result, clients should constantly consider the value of a consultant's early construction involvement, which can save time and money and improve quality.

There are different multi-criteria decision-making techniques available. One of these techniques, fuzzy TOPSIS, is appropriate for tackling consultant evaluation and selection problems. Fuzzy TOPSIS is a hybrid technique in which fuzzy logic is used to manage linguistic variables and TOPSIS is applied to perform systematic mathematical computations to determine the ranking of different consultants. Due to its ability to deal with ambiguous or inaccurate inputs, fuzzy logic can be used in circumstances where there are uncertainties (Babu et al., 2006). The Technique for Order of Preference by Similarity to Ideal Solution is the full name of the TOPSIS method, which explains how it works. It is based on the idea that the distance between the chosen option and the positive ideal solution must be as small as possible, while the distance between the anti-ideal solution and the same selected option must be as large as possible (Hwang & Yoon, 1981).

1.2 Problem Statement

The fundamental difficulty with lowest bid procurement is that focusing solely on price affects quality and overlooks the importance of other factors such as communications management, schedule control approach, and proposed project team credentials in ensuring project success. For best value procurement, which takes into consideration both price and non-price criteria, owners end up using the former as the differentiating factor between consultants. Therefore, the most appropriate method for selecting competent consultants is one that fully eliminates price as an evaluation component, as QBS does. Although QBS improves the consultant procurement process (Christodoulou et al., 2004), it is not widely adopted for consultant selection. Owners are concerned about QBS because of the subjectivity issue associated with non-price criteria.

In general, industry practices and research prioritize some evaluation factors while ignoring others. However, for effective evaluation of consultants, all factors must be covered to conduct a thorough assessment and make an accurate judgment. Furthermore, because consultant evaluation criteria are of qualitative nature, they are hard to measure. Therefore, there is a need for an analytical model that minimizes subjectivity in the decision-making process and can be utilized in different projects. The automated system should be able to objectively aid owners in selecting qualified consultants, while also allowing for some flexibility and adaptation so that it can be used for projects with varying characteristics.

1.3 Research Objectives

To address the research gap, the following are the research objectives: (1) utilization of QBS for consultant selection with minimal subjectivity, (2) establishment of a standard, comprehensive set of consultant evaluation criteria, (3) determination of a proper way to measure the evaluation criteria, which are of qualitative nature, (4) improvement of consistency, transparency, and fairness in the consultant evaluation process, and (5) development of an automated decision support system, using the fuzzy TOPSIS technique, to help owners evaluate and rank qualified consultants.

1.4 Research Methodology

1.4.1 Overview of the Research Methodology

The research methodology consisted of three main phases: an extensive literature review in the first phase, the development of a theoretical model in the second phase, and the construction of a computerized comprehensive model in the third phase to objectively evaluate and rank different consultants. The research methodology is summarized in Figure 1.1.

1.4.2 Phase 1 of the Research Methodology

Since there are common evaluation criteria between consultants and contractors, such as the relevant experience of both the firm and the proposed project team, a thorough review of the literature was conducted during the first phase of the research to identify the most important criteria and sub-criteria used to evaluate them. Different research papers were then checked to determine the most appropriate decision-making technique for dealing with the outlined problem of consultant evaluation and achieving the main aim of developing a decision support system to objectively assist in the consultant selection process.

1.4.3 Phase 2 of the Research Methodology

85 client documents, mainly request for proposals (RFPs), used by industry practitioners to evaluate consultants for detailed engineering and design services for various projects, were carefully examined for the theoretical model construction during the second phase of the research. These documents' criteria and sub-criteria were thoroughly checked, and criteria were classified into categories (e.g., technical criteria category) and a criteria breakdown structure was constructed. Statistical analysis was then performed for the criteria weights found in the analyzed dataset to obtain proper weights to recommend to the decision-maker during evaluation.

The project management knowledge areas described in PMBOK Guide (2013) were also analyzed, with the ones relevant at this early stage (i.e., bidding) being taken into account due to their importance in identifying qualified consultants (e.g., stakeholder management, quality management, etc.)

Pre-evaluation inquiries, in the form of yes/no questions were identified as a means of screening and shortlisting consultants for the detailed evaluation process. Finally, the entire theoretical framework was validated by industry experts.

1.4.4 Phase 3 of the Research Methodology

The third phase of the research entails the creation of an analytical computational model that employs the fuzzy TOPSIS technique using the Python (PyCharm) programming language. First, research papers, project management publications, and descriptions of evaluation criteria and assessment requirements in the analyzed dataset (i.e., RFPs) were used to identify the evaluation rules for objectively measuring different criteria. The rules gleaned from research articles and project management books were described as practices or steps for correctly checking or managing an area, not as evaluation rules (e.g., use of building information modeling BIM for communications management).

To obtain a performance rating for each criterion with minimal subjectivity, each criterion has a certain number of evaluation rules with pre-defined scores. Depending on the relative importance of each rule, the assigned scores differ from one rule to another, with a total score equal to 100 for all the rules of each criterion. The decision-maker will be requested to check the evaluation rules and indicate whether or not the consultant meets the requirements of each rule. As a result, linguistic scores (low, medium, and high) will be generated automatically. Calculations of the fuzzy TOPSIS method will then take place, and consultants will be ranked from the most to the least qualified. Microsoft Excel was also used to develop a fuzzy TOPSIS model, which yielded the same results as the Python model computations.

The decision support system provides an overall ranking, a ranking based only on technical criteria, and a ranking based solely on managerial and organizational criteria.

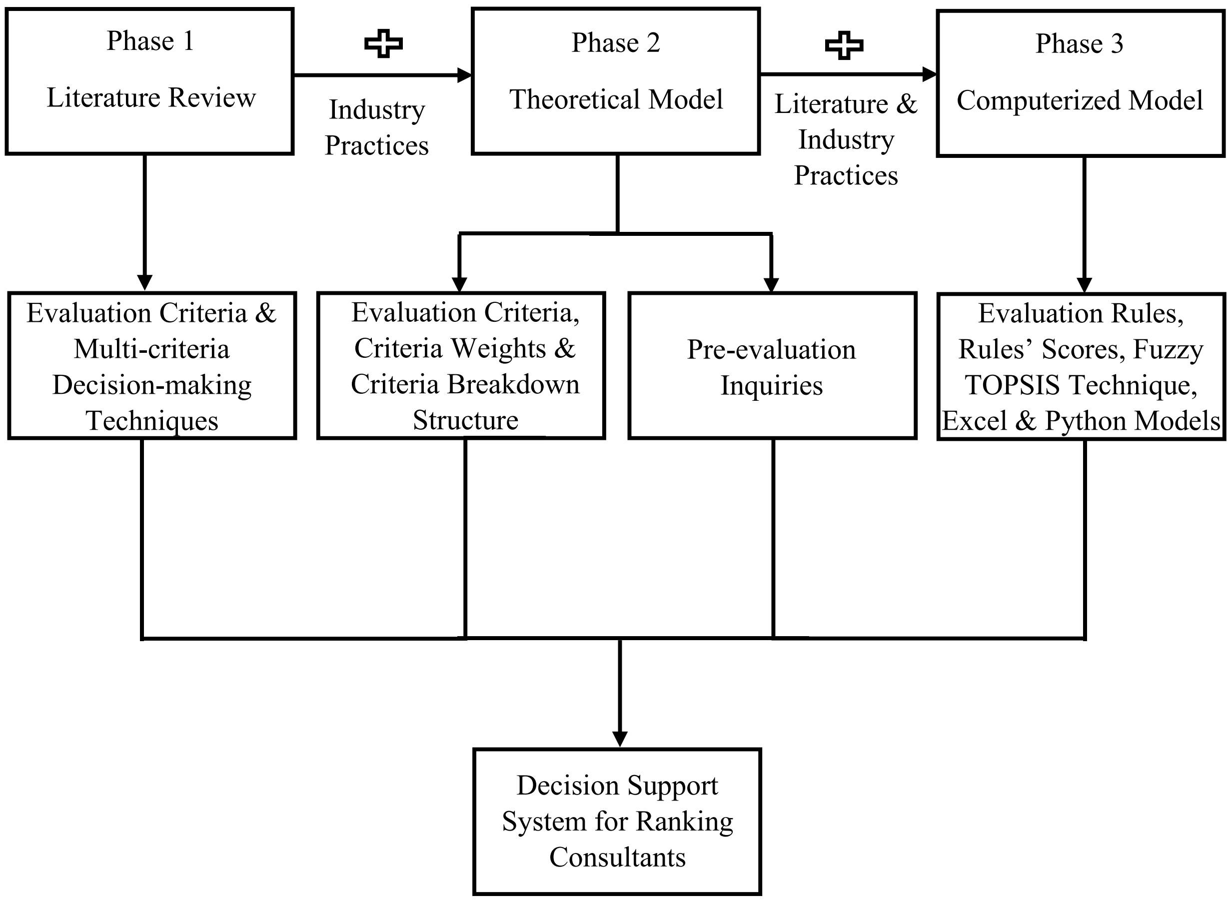

Figure 1.1 Research Methodology

1.5 Research Contributions

1.5.1 Academic Contributions

The following are considered among the academic contributions: (1) identification of evaluation rules for measuring qualitative criteria, (2) application of a state-of-the-art decision-making technique to solve an important real-life decision-making problem, where fuzzy TOPSIS approach was utilized in a way that minimizes subjectivity, adds rationale, and improves fairness in the decision making process, and (3) utilization of artificial intelligence through the implementation of the fuzzy logic technique, where trapezoidal fuzzy numbers were found to be more suitable than triangular fuzzy numbers for the consultant evaluation and selection problem because the trapezoid provides a range of maximum values whereas the triangle has one maximum value only (i.e., the apex of the triangle); hence the problem is brought closer to reality by using the trapezoid shape.

1.5.2 Industrial Contributions

The contributions to the industry are as follows: (1) identification of a complete set of consultant evaluation criteria, and classification of criteria into two main categories: (a) technical criteria, and (b) managerial and organizational criteria, with their weights, 47% for the former and 53% for the latter, derived from a statistical analysis of a significant number of client documents used to evaluate consultants. This results in standardizing the decision-making process and improving its consistency, (2) construction of an automated analytical model for consultant evaluation and ranking using the Python programming language. The developed model minimizes subjectivity and bias and improves transparency in the decision-making process so that owners can implement the QBS method. It also ranks consultants on two levels: an overall ranking (the highest level), a separate ranking for the technical criteria, and a ranking for the managerial and organizational criteria. This is advantageous, especially if two consultants, for example, have a close overall ranking; a lower level of ranking (category-wise) is required for a better judgment, and (3) consideration of adaptability and flexibility in the developed decision support system, allowing the decision-maker to insert the preferred criteria weights and exclude the non-applicable evaluation rules, if any, based on the project needs and requirements.

1.6 Thesis Organization

This thesis is divided into seven chapters, the first of which is the Introduction. The subsequent chapters' contents are summarized as follows:

- Chapter 2: Literature Review – Describes the common procurement methods for selecting consultants, the various criteria and sub-criteria for evaluating consultants and contractors, and different decision-making techniques.
- Chapter 3: Development of the Conceptual Model of the Decision Support System – Explains in detail how the theoretical framework, which includes all the criteria, sub-criteria, and criteria weights, was created.
- Chapter 4: Establishment of Evaluation Rules for Measuring Criteria – Defines various rules for measuring all the consultant evaluation criteria that are known to be qualitative.
- Chapter 5: Development of a Computerized Analytical Model for Consultant Evaluation and Ranking – Explains thoroughly how the computational model for evaluating and ranking consultants is constructed using TOPSIS in fuzzy environment.
- Chapter 6: Application of the Developed Decision Support System – Presents a detailed example of how the constructed decision support system evaluates and ranks consultants.
- Chapter 7: Conclusion – Provides a summary of the work completed under this thesis, as well as the research conclusion, limitations, and recommendations for future work.

Chapter 2: Literature Review

2.1 Introduction

The literature review chapter covers 3 main points. Different procurement methods for selection of professional services are first defined, with a comparison between the most common ones. Following that, several evaluation and selection criteria are addressed, along with certain weightings for some of them. The third point addresses a variety of evaluation techniques that can be utilized for consultant selection. A summary is provided at the end of this chapter to explain the limitations of some of the previous work and introduce what will be done in this research.

2.2 Procurement Methods

2.2.1 Overview of Procurement Methods

Services are intangible, and this is considered the most prevalent assumption that distinguishes services from goods. In other words, services are performances, and there is no possibility to taste, see, touch, feel, or examine them in the same way goods can. Also, saving and storing services is unattainable (West, 1997). Procurement of architectural and engineering services is an example of the procurement of professional services and can be referred to as the consultant evaluation and selection process.

No matter which project delivery method is selected, the procurement method significantly affects the project performance (El Wardani et al., 2006). The commonly adopted project delivery methods are Design-Build (DB), Design-Bid-Build (DBB), and Construction Management at Risk (CMAR) (Chinowsky & Kingsley, 2009). The choice of a suitable procurement method for a project depends on many factors, as this can reduce risks such as not meeting the expectations of the owner, choosing an improper DB team, and underperforming in the project (El Wardani et al., 2006). Different procurement methods include Low Bid, Qualifications-Based Selection, Best-Value, and Sole Source (Chinowsky & Kingsley, 2009).

2.2.2 Lowest Bid Procurement

Clients often select consultants based on price rather than qualifications, and public firms ordinarily base their selections on price if it is included as a selection criterion for negotiations (Kasma, 1987). In a competitive bidding process, selecting a contractor based on price does not assure a suitable quality and price of the products (Lo & Yan, 2009), since the lowest bid may not be the most qualified (Kasma, 1987).

Economic and political pressures to save money play a major role in the selection process. However, money is unable to measure the value of engineering services. Also, costs resulting from poor construction supervision, mismanagement of contract documents, or an engineering mistake might be substantially larger than the money saved by selecting the consultant with the lowest price (Kasma, 1987).

A commonly encountered problem in the traditional price-based bidding process is that contractors tend to offer unrealistically low bids. A solution to this is to adopt another procurement method instead known as Qualifications-Based Selection (QBS), which is quality dependent rather than price (Lo & Yan, 2009).

2.2.3 Qualifications-Based Selection (QBS)

QBS was founded in 1972 in the U.S. as a federal law to enhance the consultant procurement process (Christodoulou et al., 2004) by selecting consultants according to their capability and experience (Lines & Shalwani, 2017). QBS works with all project delivery methods (Chinowsky

& Kingsley, 2009), and can be adopted not only for consultant selection but for contractors as well (Manoliadis et al., 2009). Moreover, whether it is a consultant or a contractor selection process, QBS is the most appropriate approach for specialized construction and DB projects due to their nature (Manoliadis et al., 2009).

In the QBS system, public funds are dealt with in a careful and wise manner, and the greatest professional services are provided at an acceptable cost. In addition, all eligible competitors get the chance to be evaluated in the same manner and selected based on their qualifications and pre-determined criteria. Moreover, QBS is beneficial for city officials, because choosing the most suitable professional services is a tough decision and the selection process involves both subjectivity and objectivity (Rollins, 2007).

To examine how the implementation of the QBS method can impact the market competition and what the prices offered by the contractors will be in case QBS is used, a simulation model was designed by Lo and Yan (2009) to carry out this analysis. It was concluded that for a QBS system to be effective by focusing on the quality of the project, the selection criteria should not consider the price because of the problems associated with very low bids. In addition, the past performance of contractors and the assessment of their qualifications are related in a significant way that determines the effectiveness of the QBS approach. Hence, the contractor's performance in previous projects should be accurately analyzed during the bidding stage (Lo & Yan, 2009).

2.2.4 Best Value Procurement

Another type of procurement is known as best value. In best value procurement, there are many factors including price that contribute to the choice of the contractor, unlike lowest bid procurement, which is solely based on price (Yu & Wang, 2012). Best value procurement aims to accomplish several project objectives such as ensuring quality. It also aids at enhancing the project performance (Gransberg et al.,-2007). Additionally, risk mitigation, which takes place in best value procurement provides a higher project value (Storteboom et al., 2017).

2.2.5 Sole Source Selection

A contract is established with a specific consultancy firm for a certain period of time in sole source selection (e.g., a two-year contract), as explained by Chinowsky and Kingsley (2009). The same authors clarified that during that time, all engineering works will be carried out by that firm under a specific budget. However, the amount of money that needs to be agreed upon is the problem (Chinowsky & Kingsley, 2009).

2.2.6 Comparison between Procurement Methods

Usually, the selection of a contractor depends mainly on price (Sawyer, 2014). Clients tend to seek guidance from others or depend on long term relations because non-price criteria are usually hard to specify and evaluate; however, informal data usage is limited and controlled by the public procurement regulation (Sporrong, 2011).

Consultants place great efforts trying to minimize the weight of the fee criterion when owners choose best value procurement (Lines & Shalwani, 2017). However, there are many well-known organizations that encourage and support the QBS system, such as the American Council of Engineering Companies (ACEC), American Institute of Architects (AIA), American Public Works Association (APWA), United States Army Corps of Engineers (USACOE), Federal Highway Administration (FHWA) (AIA, 2015). For instance, APWA (n.d.) explained that in contrast with price, the most excellent project consultancy services to be provided to the public can be achieved when a QBS system is implemented.

Not only does QBS give room for more flexibility and creativity, but also it reduces the possibility of encountering disputes and litigation (APWA, n.d.). Similarly, Manoliadis et al. (2009) mentioned the high flexibility level in QBS and added the "multifactored decision-making capability" that QBS has in comparison with competitive bidding or any other frequently applied cost-based methods. Unlike competitive bidding, which assumes that there is no difference between suppliers or service providers, QBS disagrees (Christodoulou et al., 2004). That is because, in case of professional services, service providers include people whose capabilities substantially impact the final product's quality (Christodoulou et al., 2004).

More strength points in QBS include its fairness and objectivity, and its simplicity and easiness to understand and apply. It is also well-established and justifiable. The executive director, Mr. Jerry Deschane, League of Wisconsin Municipalities, stated that "Communities that utilize QBS report their long-term costs are lower" because QBS ensures quality (AIA, 2015).

2.3 Consultant Qualifications

2.3.1 Common Consultant Evaluation Criteria

Whether projects are simple or complex, there are three criteria indicated by Sporrong (2011) as the most favored non-price evaluation criteria to be used in the bidding stage: individual experience of key project team members, their education, and personality-related criteria. Additionally, the quality and costs of construction are significantly impacted by the consultants' attitudes, dedication, and competence (Sporrong, 2011). According to Sawyer (2014), the three main classes of evaluation criteria are technical capacity and previous performance, key personnel, and fee. However, the author in their research deduced that the key personnel aspect, in the form of an interview process, is statistically more significant than the fee (Sawyer, 2014).

Day & Barksdale (1992) compiled a list of the criteria to consider when selecting a professional services firm. The first main criterion includes experience, competence, and expertise, having the following as its sub-criteria: firm reputation, management competence, visible and active principals, and client oriented, staff capabilities, design team's technical ability, and team qualifications. Secondly, comprehension of the client requirements; comprehension of the client project and standards, creativity, and project knowledge beyond RFP all form this criterion. The third major criterion is communications, interaction, and relationship, which includes trust and integrity, good presentation, chemistry and relationship, ability to work as a team, and good listener. Finally, contractual and administrative conformance is the fourth and last major aspect, with firm workload, ability to meet schedule, efficiency, and price being its sub-criteria (Day & Barksdale, 1992)

Similarly, Cheung et al. (2002) listed four primary evaluation criteria with several sub-criteria under each one. Firm qualifications, financial stability, reputation, technical competence, similar project experience, number of similar projects completed, and award are all sub-criteria falling under the firm background criterion. Budget control, schedule control, and quality of work belong to the past performance criterion. In addition, capacity to perform the work is considered a main criterion including physical resources, qualified personnel availability, professional experience/qualifications, present number of contracts, current workload, and firm size. The last principal criterion is project approach; budget control approaches, time schedule approaches, quality approaches, comprehension of project requirements, and design approach/ methodology are all part of this criterion. Other criteria mentioned are client-consultant previous working relationship, taking project ownership, key staff to be allocated for the project, and price (Cheung et al., 2002).

Technical skills, management skills, relevant experience, knowledge of business, and implementation cost are five total quality management (TQM) consultant selection criteria, according to Saremi et al. (2009). Technical skills refer to both the system and personnel skills, and management skills comprise organization, economic stability, certificates, and acceptable insurance. For the knowledge of business, it includes strategies, markets, and processes (Saremi et al., 2009). Two of the design-related criteria mentioned by Sporrong (2011) are technical aspects of design and aesthetic aspects of design. In addition, embeddedness, as explained by Chinowsky and Kingsley (2009), is a way of measuring the owner-consultant firm's ongoing working relationship. The authors also brought attention to the importance of the trust relationship between the owner and the design team (Chinowsky & Kingsley, 2009)

Kasma (1987) described five criteria to be considered in consultant selection. First, firm technical experience, which comprises both general and relevant projects. The second aspect is the past performance and reputation criterion, where the total years of work should be looked at and, if possible, on-site inspections should take place for projects previously performed by the consultant. Also, performance quality should be checked from client references, staff operating a project which involved that consultant should be contacted, and the likelihood to backup errors they made should be considered. The third criterion, staffing, includes adequate staff, equipment, and facilities availability for the project, as well as the project team members' names, qualifications, and service with that consultant firm. Project approach and objectives is the fourth significant criterion; project concept, project work approach, project site familiarity, and project time schedule are all aspects of this criterion. Finally, proximity, which denotes the time distance between the office of the consultant and the project, is the last criterion and includes whether on-site human resources are expected or not (Kasma, 1987).

According to Ling (2002), the three critical variables which are required to forecast the consultant performance in a DB project are the capability of the consultant to solve an issue and the project strategy, the time the consultant takes to complete the design drawings, and the consultant's interest level in dealing with a complex task. Furthermore, Ling et al. (2003) found that task performance and contextual performance are two important factors that consultants must excel in to able to manage a DB project. The authors also added the competitive prices and contractor-consultant relationship aspects, since contractors are the ones that select consultants for DB projects (Ling et al., 2003).

Doloi (2009) deduced some performance-related factors to assist in contractor selection. These factors are previous performance, firm capability, planning and control, quality management, soundness of business and workforce, risk management, and commitment and dedication. Also, Abdelrahman et al. (2008) gathered various contractor evaluation criteria. Initial capital cost, project duration, staff experience, past performance, project management plan, quality management plan, environmental considerations, and technical proposal responsiveness are some of these criteria (Abdelrahman et al., 2008). Clearly, the same criteria can be used in the consultant evaluation process.

The ten most significant contractor prequalification criteria, as advised by Ng and Skitmore (1999), are performance, fraudulent activity, management capability, financial stability, firm stability, competitiveness, the standard of quality, work progress, relationship with client, and failed contract. Some other criteria listed by the same authors include health and safety, resources, response to instruction, previous debarment, reputation, work capacity, quality assurance and control, co-operative outlook, credit rating, technology level, procurement method, working capital, location, years of work, number of previous bids, and claims and contractual dispute (Ng & Skitmore, 1999). Lo et al. (2007) highlighted that beyond contractual reward (BCR) is a way that contractors count on through cutting corners and claims after project award to compensate for the low bids they offer to win the project in case of competitive bidding.

2.3.2 Uncommon Consultant Evaluation Criteria

2.3.2.1 Overview of Uncommon Evaluation Criteria

Not long ago, sustainability and innovation have been given attention in research as issues of political interest, where the role of public procurement for these matters is analyzed (Sporrong, 2011). The impact that the construction industry has on the environment is massive, and ecological and societal concerns are increasing in a way that pushes construction to become green (Badi & Murtagh, 2019).

From an operational perspective, supply chains involve extracting and utilizing raw materials from the natural environment (Fortes, 2009). The 1980s quality revolution and the 1990s supply-chain revolution have brought out the importance of considering the environment in ongoing work (Srivastava, 2007). Green supply indicates how innovations in supply chain management and industrial purchasing could be thought about in connection with the environment (Green et al., 1996). Green supply chain management (GSCM) can integrate environmental considerations into supply chain management (Srivastava, 2007). This comprises product design, material sourcing and selection, manufacturing processes, final product delivery to customers, and product end-of-life management after its useful life (Srivastava, 2007).

2.3.2.2 Green Design

Green design, also known as design for the environment or life cycle design (Glantschnig, 1994), is a significant sub-topic to GSCM, which refers to the process of creating a product or service that promotes environmental consciousness (Fortes, 2009). It is a substantial concept that adopts methods which aim to produce goods and services with the least amount of environmental effect possible (Glantschnig, 1994). Green design tools should ease the way in which design for environment can be implemented, and designers should be able to enhance the products' environmental features without the need to be environmental science and impact analysis experts (Glantschnig, 1994).

2.3.2.3 Green Purchasing and Sustainability

Companies incorporate environmental criteria in their purchasing strategies, including approaches for assessing suppliers which look at the environmental performance of the supplier and variations in performance over the long run (Green et al., 1996). Environmental concerns as well as the high resource consumption have triggered the need to adopt sustainable construction approaches including the use of sustainable materials (Govindan et al., 2016).

Green purchasing is an environmentally conscious purchasing strategy that eliminates waste sources and encourages the recycling and reclamation of acquired materials without jeopardizing the materials' performance requirements (Min & Galle, 2001). GSCM, according to Ojo et al. (2014), is an antidote for sustainability, as it aids at decreasing costs and attaining a competitive advantage for construction companies in Nigeria. Also, in China companies are applying GSCM practices to achieve better performance, especially that globalization generated pressure and pushed Chinese firms to enhance their environmental performance while balancing economic and environmental performance (Zhu & Sarkis, 2004).

Sustainable procurement by the public sector is being supported for different reasons including the decrease in the environmental and social consequences, and a motivation for the private sector to consider sustainability (Brammer & Walker, 2011). The purchasing approach followed by purchasing professionals has been reevaluated due to the ecosystem quality problems that brought attention to a renewed focus on environmentalism (Min & Galle, 2001). Furthermore, Shen et al. (2017) observed that marketing benefits, market Pressure, and internal pressure in the company are three main factors to the green procurement practice. The authors added that real estate developers choose green procurement due to policy pressure, marketing benefits, as well as business benefits, with the property sector being one of the major green building material consumers (Shen et al., 2017).

Nevertheless, engaging sustainability is known to cost more, which can be a financial concern for the majority of the public sector firms that usually have budget constraints (Brammer & Walker, 2011). A survey conducted by Min and Galle (1997) revealed that the main obstacles to successful green purchasing are related to revenues and costs, according to the respondents' rating to how severe each obstacle is. These revenues and costs are presented in the form of costly environmental programs as well as uneconomical recycling and reusing. Therefore, the authors pointed out that the possible economic benefits of green purchasing are not entirely noticed by a lot of purchasing specialists who also have a wrong idea about the cost of initiating and implementing green purchasing programs (Min & Galle, 1997).

In many cases, pollution is considered economic waste. That is because an environment that is contaminated with dangerous substances or any other pollutants indicates an inefficient or ineffective utilization of resources, as explained by Porter and van der Linde (1995). Consequently, additional tasks with zero value to customers and extra cost will be carried out by the companies, such as handling and discharges' disposal (Porter & van der Linde, 1995). Moreover, energy and resource savings are two major benefits of choosing green building materials over the traditional ones (Shen et al., 2017). Energy saving is vital due to the high energy use by buildings and related emissions (Lucon et al., 2014).

2.3.2.4 Innovation

The relation between procurement and innovation is not cognized by city officials, according to Lember et al. (2011). Also, local authorities choose to avoid the risks associated with supporting and encouraging innovation through public procurement (Lember et al., 2011). As mentioned by Porter and van der Linde (1995), people are still trying to comprehend how innovation can not only improve quality but reduce cost as well. Previously, it was assumed that the design of the product and the processes of production were both fixed, and it was thought that better quality can only be obtained by inspection and rework of unavoidable defects, which is costly. However, it is now believed that defects indicate inefficiency in the product and process design, and efforts are made in order for quality to be built into the whole process (Porter & van der Linde, 1995). At the outset of a new technology, the involvement of central and local government could be regarded as a facilitator for innovation processes because this might be advantageous socially and economically (Lember et al., 2011).

2.3.3 Evaluation Criteria Weights

2.3.3.1 Recommendations for Criteria Weights

Choosing appropriate weights for the evaluation criteria is crucial. According to Kasma (1987), each of the three aspects of firm technical experience, past performance and reputation, and project approach and objectives accounts for 25% of the total rating. Staffing constitutes 20%, with the remaining 5% going to proximity (Kasma, 1987). ACEC-BC (2016) proposed having 20-40 % on project team composition and qualifications, 30-50% on project comprehension and methodology, and 10-30% on relevant project experience and previous performance.

2.3.3.2 Relationship between Project Characteristics and Criteria Weights

It was noted by Cheung et al. (2002) that the project type is an essential factor in determining the weights of the consultant evaluation criteria for the reason that requirements on the design team vary from one project category to another. The authors added that the project size also impacts the weights, and therefore the present workload of the firm as well as the qualified staff availability are two critical criteria in case small-size firms are willing to take responsibility for large-scale projects (Cheung et al., 2002). However, Kasma (1987) pointed out that the firm's age or size is not necessarily a top concern for every project.

2.4 Consultant Evaluation Techniques

2.4.1 Overview of Evaluation Techniques

Project success is measured through three main indicators: budget, schedule, and quality, where the choice of the right architect/engineer is critical for success (Ling, 2002). To be able to choose the most suitable consultant for a job, a multi-criteria decision-making (MCDM) technique should be applied (Saremi et al., 2009), where MCDM indicates “making decisions in the presence of multiple, usually conflicting, criteria” (Hwang & Yoon, 1981).

According to Babu et al. (2006), MCDM can be classified into two main groups: Multi-Attribute Decision-Making (MADM) and Multi-Objective Decision-Making (MODM). MADM deals with problems that have discrete decision spaces, and a certain number of attributes are used to elucidate different alternatives, where these alternatives are decided upon in advance. In contrast, MODM focuses on problems with continuous decision spaces, and a mathematical programming system is what tacitly describes design alternatives. In MADM, alternatives' "prioritized attributes" determine the choice of an alternative among others, whereas "prioritized objectives" in MODM are needed to optimize one or more alternatives. An objective can also be an attribute with a direction (Babu et al., 2006).

Several MCDM methods include data envelopment analysis (DEA), artificial neural network (ANN) based techniques, analytic network process (ANP), analytical hierarchy process (AHP), fuzzy methods, ELECTRE (Elimination Et Choix Traduisant la REalite – ELimination and Choice Expressing the Reality), PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation), simple multi-attribute rating technique (SMART), and the simplest approach that known as the weighted sum model (WSM) (Agarwal et al., 2011). Additionally, TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), Lexicographic, and Goal Programming are other MCDM techniques (Babu et al., 2006).

2.4.2 Introduction to Decision-Making Techniques

Babu et al. (2006) explained that approaches to estimating complicated probabilities under uncertainty are provided by decision making theory, where the degree of uncertainty is a crucial factor in making a decision. The decision-making rule aids at choosing the preferable alternative, categorizing alternatives and placing them in a priority order, and ranking of alternatives (Babu et al., 2006). According to Jahanshahloo et al. (2006), MCDM involves several steps: creation of a system evaluation criteria which links the capabilities of the system with the targets, formation of alternative systems to achieve the targets, assessment of the different alternatives in connection with the criterion functions' significance, use of a multi-criteria evaluation technique, and finally the selection of the most suitable alternative. However, new information should be collected, and the process should be repeated in case there is no approval on the final solution (Jahanshahloo et al., 2006).

Saaty (2008) clarified that the decision-making process requires measuring both tangibles and intangibles, where many of the latter must be traded-off while making decisions. The problem needs to be identified and the requirement for this decision as well as its objective must be explicit. Also, the decision criteria, sub-criteria, groups impacted, and stakeholders have to be specified. To be able to find the most suitable alternative and make the right decision, all possible choices should be first identified. Additionally, relative priorities are essential in the decision-making process, because a lot of primary factors are unmeasurable. Hence, knowing how relative priorities can be obtained is necessary (Saaty, 2008).

Jahanshahloo et al. (2006) stated that while employing a multi-criteria evaluation technique, the relative significance of each criterion should be decided upon by the decision-makers. That can take place using criteria weights. There is no economic importance for these weights in MCDM; however, they are of value in terms of modeling the actual decision-making features (the preference structure) (Jahanshahloo et al., 2006).

2.4.3 Analytical Hierarchy Process (AHP)

AHP is a very famous method introduced by Thomas Saaty and can be used to measure intangible or qualitative criteria (Figueira et al., 2016). The three rules AHP follows are building a hierarchy, setting of priority, and rational consistency (Macharis et al., 2004). As indicated by Saaty (2008), in AHP, pairwise comparisons take place and experts' judgments are essential as they are needed to obtain priority scales, where intangibles are comparatively measured through these scales. A scale of absolute judgments is utilized for comparisons. This scale ranges from 1 (equal importance) to 9 (extreme importance) and reflects how much more one element dominates another in terms of a certain attribute. In AHP, inconsistency in judgments might be found; therefore, a problem with this method is the difficulty of measuring inconsistency and getting better judgments which would improve the consistency accordingly (Saaty, 2008).

2.4.4 Analytic Network Process (ANP)

Thomas Saaty derived ANP from AHP, where AHP is a special case of ANP, according to Figueira et al. (2016). In ANP, combined priority ratio scales are obtained from single ratio scales, which describe relative measurements of the impact of interacting elements, and specific criteria determine such interactions. Clusters of elements are dependent, and the result of this dependency is expressed through the ANP (Figueira et al., 2016).

2.4.5 Outranking Methods

2.4.5.1 Overview of Outranking Methods

Initially, outranking methods were introduced in France in the late sixties due to the inability to solve practical problems using the value function method (Bouyssou, 2009). Brans and Vincke (1985) explained that outranking methods aim to improve the dominance relation of a multi-criteria problem which is insufficient for problem solving because it relies on the consensus of opinions. Such improvement takes place by applying a majority principle rather than the consensus of opinions. An outranking method comprises two phases, where an outranking relation is built in the first phase, and this relation is utilized in the second phase to help the decision-maker (Brans & Vincke, 1985). The outranking or preference relation is constructed among alternatives that are assessed on different attributes (Bouyssou, 2009).

2.4.5.2 ELECTRE

The use of ELECTRE methods has taken place for Multiple Criteria Decision-Aiding (MCDA) in several real-world decision problems in different fields such as finance, environment, water management, agriculture, transportation, and project selection (Figueira et al., 2010). In addition, ELECTRE methods were applied to solve several concrete problems, as mentioned by Brans and Vincke (1985). Nevertheless, many parameters are needed in these methods, and so they are considered complicated, where the decision-maker needs to fix their values. While some values can be easily fixed as they have an actual economic significance, other important ones have a technical character only, and the results are sometimes incomprehensibly impacted (Brans & Vincke, 1985).

2.4.5.3 PROMETHEE

PROMETHEE methods are outranking methods for MCDM (Brans & Vincke, 1985). They are modified techniques that were introduced due to the difficulties encountered in the ELECTRE methods, as clarified by Brans and Vincke (1985). The major characteristics of these approaches are clarity, simplicity, and stability (Brans et al., 1986) so that the decision-maker can comprehend them easily (Brans & Vincke, 1985).

As indicated by Brans et al. (1986), a valued outranking relation is built using the concept of generalized criterion. Also, there is an economic meaning to all the parameters to be defined, which allows the decision-maker to fix them with no difficulty (Brans et al., 1986). A preference index is used to create a valued outranking graph, where this graph is used to solve the ranking problem with the implementation of either PROMETHEE I or PROMETHEE II (Brans & Vincke, 1985). On the group of possible actions, the former gives a partial preorder, and the latter provides a complete preorder (Brans & Vincke, 1985).

2.4.6 TOPSIS

TOPSIS was introduced by Yoon and Hwang in the early 1980s (Jahanshahloo et al., 2006). It is a multiple criteria technique that is used to determine solutions from a certain number of alternatives (Jahanshahloo et al., 2006). According to Opricovic and Tzeng (2004), TOPSIS was founded with the closeness to the ideal concept indicated by an aggregating function. In TOPSIS, the criterion functions' units are removed through vector normalization (Opricovic & Tzeng, 2004). It works with the principle that the distance between the selected alternative and the ideal solution must be minimal, whereas it should be the maximum from the negative ideal solution (Hwang & Yoon, 1981). However, the relative significance of these distances is not taken into account (Opricovic & Tzeng, 2004). The values of the performance ratings in TOPSIS, as well as the criteria weights, are precise with no approximations (Jahanshahloo et al., 2006).

The use of TOPSIS is well-known because it is easily applied (Velasquez & Hester, 2013). The authors stated that "Many of the uses seen in the literature review had TOPSIS confirm the answers proposed by other MCDM methods." In addition, they mentioned that this technique is used to quickly review other techniques or to perform as an individual decision-making tool. That is because it is simple and no matter what the problem size is, the number of steps remains the same (Velasquez & Hester, 2013).

2.4.7 Fuzzy Logic

Fuzzy logic is a decision-making technique developed by Lotfi Zadeh in 1973 (Babu et al., 2006). In Zadeh's publications, fuzzy logic is defined as fuzzy set-based approaches for large-scale approximation reasoning, and approximate reasoning is a subtopic of Artificial Intelligence (Dubois et al., 1999). According to Babu et al. (2006), fuzzy logic is used in cases where ambiguities exist, as it is can tackle inputs that are unclear or imprecise. It is also capable of examining and controlling complex systems (Babu et al., 2006).

Zadeh (1988) clarified that unlike the traditional logical systems where precision is crucial, fuzzy logic works with approximations, and the logical chains are short in length. Hence, everything in fuzzy logic is a “matter of degree.” In addition, a numerical truth value can be imprecisely described and presented by a fuzzy truth value. Several fuzzy logic applications include a linguistic variable as a fundamental concept (Zadeh, 1988). The linguistic terms representing the ratings are fuzzified, which means that they are translated into fuzzy numbers, as explained by Manoliadis et al. (2009). Then, they are combined into one fuzzy number, named the fuzzy attractiveness rating. In the end, this fuzzy number is de-fuzzified or, in other words, converted back into linguistic expressions. By that, a decision, phrased in linguistic terms that are understandable, is obtained (Manoliadis et al., 2009).

Princy and Dhenakaran (2016) explained that a fuzzy number is a generalization of a real number in that it does not link to a single number but rather to a combined set of possible values, each of which has its own range value between zero and one, known as the membership function. The ambiguous boundaries of a fuzzy set define it. Its membership function describes its properties (Princy & Dhenakaran, 2016).

Manoliadis et al. (2009) indicated that to be able to assess the importance of every single criterion and the trends of all the different aspects (e.g., market, strategy, and technology), the fuzzy logic technique should be employed by decision-makers having a top managerial role in the organization. A fuzzy-weighted average calculation seems complex and is disfavored by the managers. Computerizing this computation is required for greater accuracy as well as less processing time and chance of errors (Manoliadis et al., 2009).

2.4.8 Choosing By Advantages (CBA)

The CBA method was developed by Jim Suhr (Arroyo, 2014). It is a structured multi-criteria decision-making approach in which decisions are based on the importance of advantages among alternatives (Schöttle et al., 2019). The advantages are anchored to relevant facts in CBA, allowing decision-makers to make a sound and comprehensive decision (Schöttle et al., 2019). Arroyo et al. (2012) explained that CBA demands decision-makers to first determine the advantages of alternatives before developing their preferences. The steps in the CBA method are (1) identifying alternatives, (2) defining factors, (3) agreeing on the must-have and desirable criteria for each factor, (4) summarizing each alternative's attributes, (5) determining each alternative's advantages, (6) deciding each advantage's importance, and (7) evaluating cost data (Arroyo, 2014).

CBA aligns with lean thinking (Arroyo et al., 2012). It employs a well-defined vocabulary to ensure that the decision-making process is clear and transparent (Parrish & Tommelein, 2009). Furthermore, CBA results in fewer conflicting questions and enables stakeholders to talk about what they value in a more detailed context (Arroyo et al., 2012).

Karakhan et al. (2016) clarified that the inherent complexity of the CBA process was regarded as a major drawback and that the procedure applied in the CBA tabular method is time-consuming and complicated. In addition, CBA is incapable of assessing a single alternative because the decision is based on a comparison between the advantages of alternatives (Karakhan et al., 2016).

2.4.9 Comparison between MCDM Techniques

Different MCDM techniques were compared in a table provided by Sen et al. (2015), which includes the method name, author(s), application areas, advantages, and disadvantages. Some of this information is presented in Table 2.1. For the rank reversal issue, which is a disadvantage of the ANP method (Sen et al., 2015), it implies that when a new option is added, the ranking of the alternatives may be reversed in some situations (Macharis et al., 2004). That can also be encountered in AHP and PROMETHEE methods (Macharis et al., 2004).

Table 2.1 Comparison Between Different MCDM Techniques (Sen et al., 2015)

Technique	Author	Area	Advantage	Disadvantage
AHP	Saaty (1986)	Multi-criteria problem, public policy planning, and corporate policy	A scale that allows easy pair-wise comparison and weight calculation. More flexibility is provided	Inconsistencies between judgment and ranking criteria
ANP	Saaty (1996)	Decision-making with dependence	Independency between elements is not needed	Rank reversal and the number of judgment elicitations

Technique	Author	Area	Advantage	Disadvantage
ELECTRE	Velasquez and Hester (2013)	Environmental, energy, and transportation problems	Vagueness and uncertainty are considered	Possibility of difficulty in explaining the process and result in simple terms
PROMETHEE	Velasquez and Hester (2013)	Education, transportation, logistics, manufacturing, and assembly	Many human judgments with decisions of long-term impact are simplified. Alternatives' full and partial ranking can be obtained	No clear method for weight assignment
TOPSIS	Velasquez and Hester (2013)	Transportation, logistics, energy, manufacturing, and assembly	The number of steps does not change even if the number of attributes changes	Slight complexity in the computation

Chakraborty (2011) provided a comparison between different methods, where AHP, ELECTRE, PROMETHEE, and TOPSIS were included. The comparative performance of these techniques shows that the computational time is very high for AHP, high for both ELECTRE and PROMETHEE, and moderate for TOPSIS. In terms of the mathematical computations, they are considered maximum in AHP, while they are deemed intermediate for the remaining techniques.

AHP has low stability, whereas the other techniques have average stability. When it comes to simplicity, AHP is regarded as very critical, whereas it is considered somewhat critical for the others. The type of information, which is quantitative for TOPSIS but mixed for AHP, ELECTRE, and PROMETHEE, is the last point of comparison (Chakraborty, 2011).

2.4.10 Applications of Multi-Criteria Evaluation Techniques

AHP was the technique adopted by Cheung et al. (2002) for consultant assessment. The generally used consultant selection criteria were specified through a questionnaire survey, and the weight of each criterion was obtained from projects with the same characteristics, which were then used to construct multi-criteria models. Accordingly, the Architectural Consultant Selection System (ACSS) was a computer program developed to systematize the evaluation process (Cheung et al., 2002).

Another questionnaire survey, including different consultant evaluation criteria, was prepared by Ng and Chow (2004) to get assistance from experts on the significance of each criterion, and accordingly, criteria weights were decided upon. The development of a multi-criteria model to assess the consultant's performance took place using the Multi-Attribute Value Technique (MAVT), where the scores of consultants can assist clients in the evaluation process. In addition, these scores can be beneficial not only for pre-selection and bid evaluation but for technical evaluation, incentive and sanction, and monitor and control as well (Ng & Chow, 2004)

To enhance the process of evaluating the performance of a consultant, a fuzzy gap analysis model was developed by Chow and Ng (2007). This model provides evaluators with a comparison between what the client desires and the quality of what has already been done by the consultant to identify the gap. Previous research was used to specify the criteria concerned with the design phase of a project, with a minimum of one quantitative indicator for each criterion. The performance level for each quantitative indicator was obtained from evaluators via an empirical survey (Chow & Ng, 2007).

Manoliadis et al. (2009) used fuzzy logic along with the regular Delphi method to enhance the classic QBS approach. The assessment of experts is used by the fuzzy Delphi method (FDM) to determine the factors and their weights, where the bidders are evaluated via a fuzzy attractiveness ratio to find out whether they are convenient for the job or not (Manoliadis et al., 2009)

For an effective TQM program to take place, the consultants' assessment is crucial (Kabir & Sumi, 2014). Saremi et al. (2009) explained that in small and medium-sized enterprises (SMEs), the consultant plays a major role in the proper implementation of a TQM program. TOPSIS was used in a fuzzy environment to establish a standardized way for consultant selection. Evaluation criteria were provided by the nominal group technique (NGT). The study concluded that TOPSIS is more suitable for this type of problem in comparison with other MCDM techniques (Saremi et al., 2009).

Fuzzy analytical hierarchy process (FAHP) and PROMETHEE, were combined by Kabir and Sumi (2014) to develop a decision support tool to carry out the consultant evaluation and selection process in a systemized way. Criteria and sub-criteria weights were computed by the former method, whereas the criteria aggregation and rating of other possibilities were performed by the latter. After that, a geometrical analysis for interactive assistance (GAIA) plane was created to visualize different alternatives and criteria. It also assists in examining the strengths and weaknesses of these alternatives. An advantage of this decision support system is that there is no limitation in the amount of quantitative and qualitative attributes it can deal with at the same time (Kabir & Sumi, 2014).

Regarding DB projects, a model was developed by Ling et al. (2003) to help contractors decide on the most suitable consultant. A questionnaire was carried out to determine the necessary attributes needed to build the consultant selection model. Subsequently, the MAVT was applied in the model, where each design consultant gets an overall score, and the most appropriate consultant for the project would be the one with the highest score. Furthermore, not only the total score was computed but the individual score of each attribute as well. By that, a detailed evaluation of the strong and weak points of each consultant could be obtained (Ling et al., 2003).

Another study for DB projects was carried out by Ling (2002), where the attributes, which have an impact on the performance of the consultant, were specified. A questionnaire was then conducted to gather experts' opinions on the significance of each attribute. After that, a multiple regression model was designed to assist contractors in forecasting the architect/engineer's performance in DB projects. The performance scores, computed by the model, were compared to those provided by the DB contractors (Ling, 2002)

Boer et al. (1998) suggested that outranking methods can be an appropriate decision-making tool for supplier selection and can deal with quantitative and qualitative criteria. They explained that the ELECTRE I method considers indetermination and imprecision and that the lack of determination and precision can be tackled more subtly by using extensions such as ELECTRE III method. The criteria, criteria weights and the required information are not dictated by the outranking models, as these models only provide guidance on how to make these aspects clear. An application to these methods can be the use of an ELECTRE I model without much information and time to minimize a big list of suppliers into a smaller list that includes the good ones, and after that, an ELECTRE III model can be utilized to reach a final decision (Boer et al., 1998).

A fuzzy-AHP-TOPSIS model was developed by Wittstruck and Teuteberg (2012) and can be computerized simply by using MS excel or another software. It serves as a comprehensive way and decision-making tool for choosing recycling partners with an emphasis on environmental, social, and financial factors. The model is able to accommodate both tangible and intangible factors. The integration of AHP with fuzzy logic decreases the assessment bias that takes place in pairwise comparison. In addition, the calculation of the criteria's relative significance, as well as the determination of the partner firm which fulfills the criteria best, is carried out by TOPSIS (Wittstruck & Teuteberg, 2012).

Decision-making techniques can be used not only for consultant selection but for other applications as well such as choosing sustainable construction materials. For instance, Govindan et al. (2016) constructed a hybrid multi-criteria decision-making model, applying TOPSIS and DANP (DEMATEL-based Analytic Network Process; DEMATEL: Decision Making Trial and Evaluation Laboratory) methods, and used sustainable indicators to assess the most appropriate sustainable construction material in a region of the United Arab Emirates.

2.5 Summary and Research Gap

2.5.1 Limitations of Previous Work

Although several models were constructed in different studies to aid in the consultant selection process, some limitations of these models exist. For instance, Cheung et al. (2002), who used AHP, considered only four specific factors to be having an impact on determining the criteria weights. These factors are the nature of the client, firm size, project type, and project size. Also, data groups, which were formed based on the characteristics and the four previously mentioned factors, were not all analyzed by the model. Additionally, the designed model was intended for the private sector only (Cheung et al., 2002). Another example is for a study conducted by Kabir and Sumi (2014), who used FAHP with PROMETHEE; limitations lie in the need to include detailed criteria as well as sub-criteria of an organization, which are required for assessing consultants to obtain a more reliable decision.

For the approach used by Wittstruck and Teuteberg (2012), who developed a fuzzy-AHP-TOPSIS model for partner selection, a shortcoming is due to the rank reversal problem. Belton and Gear (1983) observed this issue in AHP, whereas De Keyser and Peeters (1996) noticed this in PROMETHEE. In addition, two other limitations of Wittstruck and Teuteberg's (2012) model are related to time. Since the evaluation matrices are assessed manually, it takes a lot of time and is liable to errors. The other time-related issue is also method-related, since in AHP, in comparison with cost-utility analysis, a lot of time is needed in the process of pairwise comparison of criteria, and the number of comparisons increases as the number of criteria increases (Wittstruck & Teuteberg, 2012).

For a model designed by Ling et al. (2003), it is restricted to selecting design consultants by DB contractors. This is because the viewpoint of construction clients or the requirements by other procurement system types may differ, and accordingly the selected consultant may not be the same. The same study also pointed out the importance of considering a qualitative strategy along with the quantitative one, which is adopted by the model, because the design is of contextual nature. Also, consultants with no past experience cannot be assessed (Ling et al., 2003).

2.5.2 Filling the Research Gap and Choosing a Suitable MCDM Approach

For a proper consultant evaluation and selection process to take place, the price factor should be eliminated. There is a need for the development of a comprehensive set of evaluation criteria and sub-criteria to systemize the process and solve the issue of inconsistency in the choice of different criteria.

Saaty (2008) clarified that when objectivity is the norm, using judgments has been regarded as a dubious practice. However, even when numbers are taken from a standard scale and are considered objective, their interpretation is always subjective (Saaty, 2008). In addition, Cheung et al. (2002) explained that in many countries high subjectivity is included in the decision-making process for consultant selection. As a result, it can be inferred that subjectivity is the primary issue in the decision-making process, and that there is a lack of a decision-support tool that objectively assesses the consultant evaluation criteria in a fair and transparent manner to produce credible judgments.

Every multi-criteria decision-making approach has benefits and drawbacks. What is crucial is to figure out which approach is best for the situation at hand. Hence, fuzzy TOPSIS is found to be a useful approach for this type of problem, which is the evaluation and selection of consultants. For TOPSIS, as explained by Yang et al. (1996), its input data are the decision matrix and the attributes' relative weights. The alternatives in TOPSIS are being ranked in a simple and systematic way, and it permits direct compensation among attributes with no limit (Yang et al., 1996). Similarly, İç (2012) highlighted the simplicity of TOPSIS and the fact that it has the capacity to provide an unambiguous preference order. Regarding fuzzy logic, it can deal with linguistic variables and is often used in conjunction with other techniques such as AHP or TOPSIS. According to Velasquez and Hester (2013), fuzzy sets deal with imprecise input and lack of information. Because of the appropriateness of fuzzy numbers and fuzzy values for representing ambiguous information, they are frequently utilized in engineering applications (Boukezzoula et al., 2007). Velasquez and Hester (2013) indicated that deficiencies found in certain multi-criteria decision analysis methods are addressed by combining different methods, which will take place in this research by implementing a hybrid fuzzy TOPSIS approach.

Chapter 3: Development of the Conceptual Model of the Decision Support System

3.1 Introduction

The objective of this research is to develop a decision support system to assist owners in selecting the most competent consultant for a given project. This tool aims to minimize subjectivity and bias in the evaluation process while also systematizing it to make it more reliable, transparent, and objective.

To create the decision-making model, industry practices and literature were studied, as illustrated in Figure 3.1. Industry practices are documents (e.g., RFPs) used by different public owners in Alberta to evaluate and select consultants. The model adopts the QBS approach and includes a standard set of criteria and sub-criteria, with weights. Factors like environmental and innovation level are considered in the model; these factors are generally not given much attention, as they are hard to define and measure. Pre-evaluation inquiries were also added, which should be answered prior to the thorough evaluation process. The model was validated by a panel of experts who are industry practitioners.

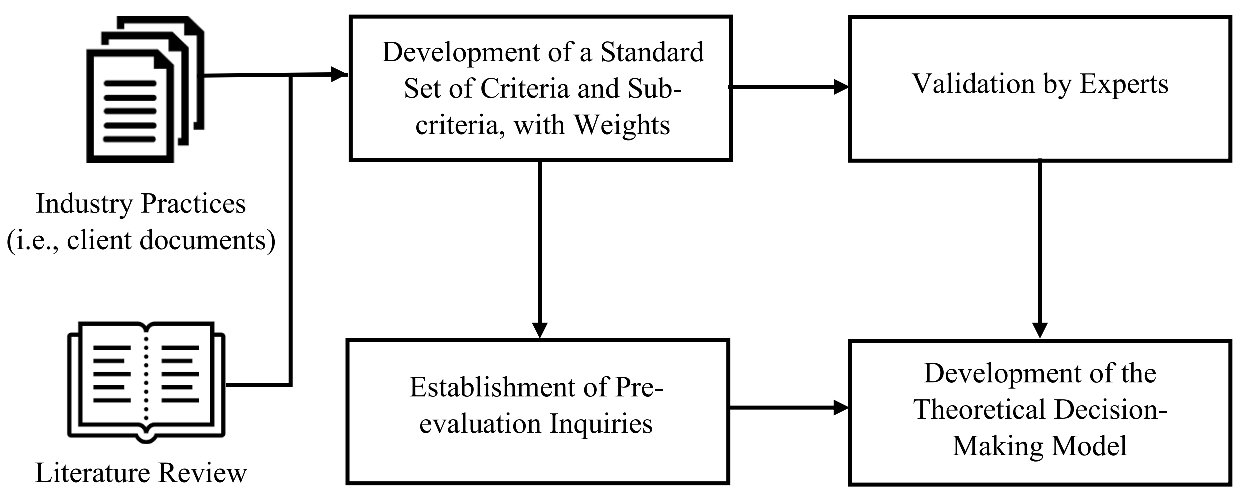

Figure 3.1 Methodology for Theoretical Model Development

3.2 Analysis of the Current Practices

A sample size of 85 client documents was investigated, including RFPs, negotiated request for proposals (NRFPs), and request for standing offers (RFSOs). The criteria and sub-criteria, as well as the weights allocated to them, were thoroughly investigated in these documents. Seven RFP documents (8.24%) were then excluded since five of them did not provide any criteria weights, and the other two RFPs only contained proposal requirements with no specific criteria.

A request for qualifications document (1.18%) was also excluded since it only included requirements. In addition, five documents (5.88%) were eliminated because they were either request for expressions of interest or request for quotations, which solely included criteria related to firm and project team credentials, demonstrated capacity, potential for relevant innovation, etc.; project specific criteria like the understanding of the project and proposed methodology were not found in these documents because they are not required at that stage.

An RFP (1.18%) was the last document to be discarded, since it had criteria weights that were considerably different from those in the other studied documents. Firm experience and qualifications, for example, were given a 7% weighting, with firm profile (4.85%) and future direction (2.15%) as sub-criteria. Risk management received 1.15%, while financial management received 1.60%. This document was deemed an outlier that might have an impact on the results, therefore it was removed. As a result, the final sample size is 71 client documents instead of 85.

Figure 3.2 shows a portion of the excel table that was built to collect all criteria and sub-criteria found in the 85 documents studied, along with their weights. Since the developed excel table is quite big to be displayed in its entirety, only part of it is presented. Document number is just a unique identifier assigned to each document. Each criterion was given some comments (the red markings beside the numbers), which included the criterion breakdown and/or description, which was later utilized for additional analysis. Furthermore, the symbol "X" in the same figure denotes that the criteria or requirements were mentioned in the document with no weight assignments, whereas "P/F" indicates a pass or fail decision with no weight. The overall weight of criteria in each document is 100%, and if no weights are specified in the document, it is represented as 0%. Certain essential sub-criteria were separated from the major ones in case they were regarded as sub-criteria in the documents (e.g., risk management). This was done so that they could be analyzed and to see how many documents accorded them importance and assigned an individual weight for each one of them.

Document Number	1	2	6	9	10	15	19	22	23	26	27	28	33	38	43	47	49	53	58	64	65	66	67	74	75	77	79	82	85
Project Comprehension and Methodology	X	20	40	X	20	30	35	25	30	20	20	40	35	35	35	40	40	45	20	20	30	30	15	X	30	35	30	60	50
Schedule Control	X			X				10															5	X	10		20		
Cost Control																													
Quality Control																													
Project Control and Organization											5										10	5							
Safety															P/F														
Communications Management																5	10	20					15						
Risk Management																							15						
Innovation and Value-added Services			10				5						5			10	10		5		10				5				5
Local Experience					20																								
Firm Relevant Project Experience	X	25				25	20		25	20		10	15	20	20					20	30	30					10		
Firm Credentials			15																20				30		5	30		10	20
Project Team Credentials	X	25	35		20	25	20	25	25	20		20	25	20	20	25			25	20	20	15	20		25	10	20	30	20
Project Leader Credentials						20	10		20			30																	
Sub-consultants	X																												
Firm and Project Team Experience																			20										
Firm and Project Team Credentials				X							55						25	20						X					
Firm's Ability to Meet Functional Expectations					10																								
Reputation of Service to Previous Clients					10																								
Client-consultant Previous Working Relationship				X																				X					
Proponent's Financial Ability				X																				X					
Proposal Quality				X				10																X					
Proponent's Health and Safety Record and Claims History				X																				X					
Price	X	30		X	20		10	15		40	20		20	25	25	20	15	15	10	40		20		X	25	25	20		5
Interview								15																					
Total Weight %	0	100	100	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0	100	100	100	100	100
Document Type	RFP	RFP	RFP	RFP	RFP	RFP	RFP	RFP	RFSO	RFP	RFP	RFSO	RFP	RFP	RFP	RFP	RFP	RFP	NRFP	RFP	RFP	RFP	RFP	RFP	RFP	RFP	RFP	RFP	RFP

Figure 3.2 Preliminary Analysis for the Criteria and Sub-criteria in the Dataset

Since QBS is the procurement method being investigated, the price criterion was removed from the documents that use it for evaluation and its weight was divided among the other criteria in the same document. For price distribution, Equation 3.1 was used.

$$w = w_0 * \frac{100}{100 - p} \tag{3.1}$$

Where w represents the criterion's new weight, w_0 is the criterion's original weight, and p denotes the price criterion's weight.

Following the same principle as the price criterion, the weight of the interview criterion was added to the other criteria weights. Only three documents out of 71 had an interview criterion, one of which was optional. Instead of eliminating the price and interview criteria, their weights were distributed across the other criteria so that all documents could be compared evenly with a total weight of 100% for each.

After the preliminary analysis, a new table was created using the final sample size of 71 documents, similar to the one shown in Figure 3.2. To reduce the overall number of evaluation criteria, relevant criteria were grouped in the new table. For instance, all aspects related to the firm, such as relevant projects and experience, as well as local experience, were combined into a single criterion called firm credentials. In addition, as explained in the next section, some assumptions and considerations were made.

3.3 Assumptions and Considerations

Assumptions and Considerations arose primarily because of the documents' lack of information and criteria descriptions, with the purpose of developing a standard set of evaluation criteria. The following are these assumptions:

1. General assumptions:

    - In case the interpretation of a criterion was not provided in a document, it was given the same description found in another document (e.g., project control and organization).

    - If the description of a major criterion had two different aspects that needed to be separated, the criterion was split into two sub-criteria with equal weights. This was the case with project control and organization, which included schedule and presentation layout of all key personnel. Hence, the former was added as part of the technical requirements, whereas the latter was included under the project team credentials.

2. Technical criteria-related assumptions:

    - According to the documents, a criterion like project comprehension and methodology was either merged into one criterion or separated into two. When just project comprehension was specified and no methodology requirement was found, project comprehension was considered to cover both comprehension and methodology.

    - For innovation and value-added services, if one of the criterion's components was missing, the criterion was still deemed to include both.

3. Managerial and Organizational criteria-related assumptions:

- If the experience criterion had a broad name (e.g., relevant project experience or experience) and did not specify whether it was required for the firm or the project team, and the same document already had a separate criterion for team credentials, the experience criterion was only considered for the firm. It was added in this case as part of the firm credentials' criterion.

- If the firm and team credentials were defined as a single criterion, and the document did not discuss any other criteria for the firm or team (or only contained local experience), the weight of this criterion was divided equally between the firm and team credentials.

- When the team's skills and experience were required in the previous project examples that the firm should provide, they were considered part of the firm credentials if the document already contained another criterion for the team. They were, however, considered for both the firm and the team if no specific criterion was mentioned in the document for the latter.

- Past performance was combined with the firm credentials in case the former was found as a separate main criterion. That is because past performance is part of the firm experience and qualifications.

- References were regarded part of the firm credentials criterion if they were found as a separate main criterion in a document.

- Instead of being a distinct criterion, local experience such as familiarity with the existing infrastructure of the town was treated as part of the firm credentials.

- Sub-consultants' qualifications, experience, and resumes were presumed to be part of the proposed project team if there was no description supplied for the proposed project team criterion in general, or if the description did not include sub-consultants. That is applicable if there will be any sub-consultants working on the project.

3.4 Identification of the Important Evaluation Criteria and Sub-criteria, and Weights

3.4.1 The Three Major Criteria Groups

Descriptions of the criteria differ between the documents and factors like schedule, risk, and communication were not always given separate weights; hence, it was difficult to perform statistical analysis for all the criteria and sub-criteria. For example, innovation and value-added services had an individual weight in only 20 documents out of the 71, which accounts for 28.17% only. Only once was a separate weight assigned to the cost control approach, and no weight was allocated particularly to environmental considerations in any of the documents.

To be able to compute the average weights utilized in all the documents, criteria at a higher level had to be employed. Hence, if there were any, evaluation criteria that belong to the same category were grouped. As a result, as shown in Figure 3.3, the three most significant groups of criteria were identified: (1) project comprehension, methodology and management systems, (2) firm credentials, and (3) project team credentials.

From the statistical analysis of the documents, project comprehension, methodology, and management systems account for an average of 47% of the total weight and include all the technical aspects and project management systems that are needed for evaluation. The firm credentials had an average weight of 25% and covers the firm qualifications, relevant experience, and past performance through relevant project examples, etc. For the credentials of the proposed project team, having a 28% average weight, it comprises both the proposed project leader and team and requires a description of the key team members, with their skills, education, relevant project experience, etc.

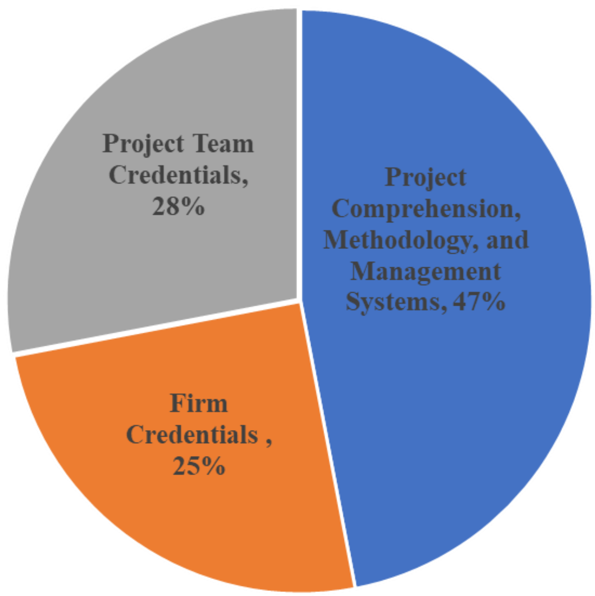

Figure 3.3 Distribution of Evaluation Criteria Weights in the Dataset

3.4.2 Proposed Criteria Breakdown Structure

Criteria for consultant evaluation were divided into two main categories: (1) technical criteria and (2) managerial and organizational criteria, as shown in Figure 3.4. The proposed division of the project comprehension, methodology, and management systems' weight (i.e., all the technical criteria), which is 47%, is 27% on the project comprehension and methodology, and 20% on the quality and project controls. The firm credentials and the project team credentials were added together under the managerial and organizational criteria, with a total weight of 53%.

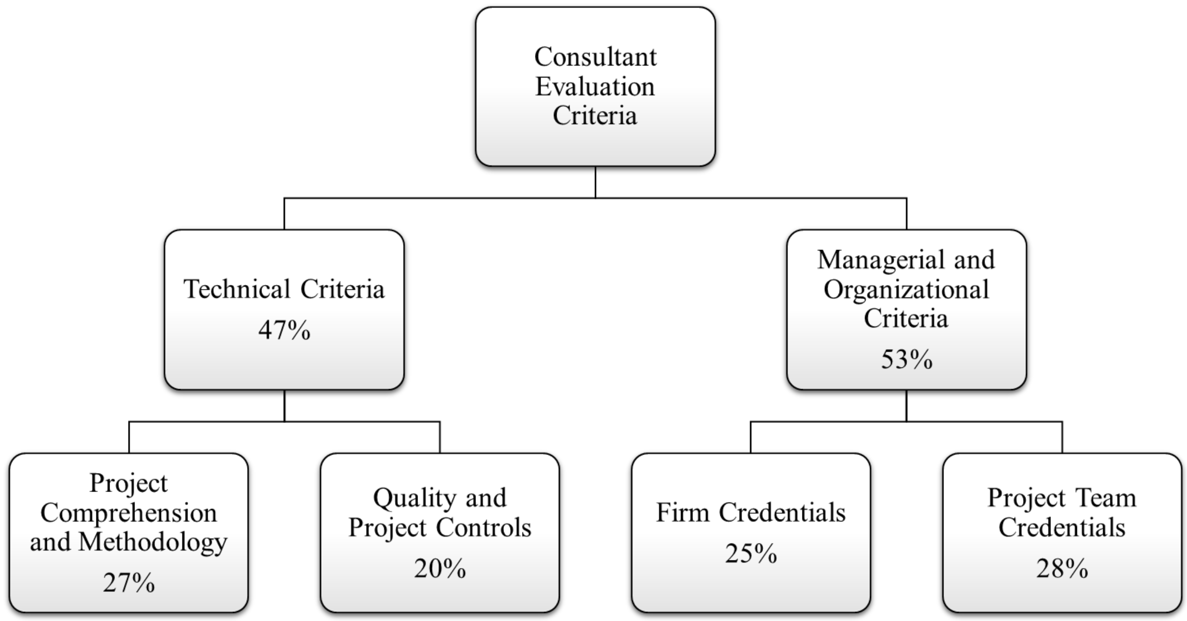

Figure 3.4 Hierarchal Classification of Evaluation Criteria

3.4.3 Detailed Description of Criteria and Sub-criteria

All the essential criteria and sub-criteria were extracted from the documents to create a standard set of criteria that clients can use to assess consultants in different projects. The aim is to include the "project management knowledge areas" as termed by PMBOK Guide (2013). The number of the knowledge areas is ten, as illustrated in Figure 3.5; however, the aspects that are applicable at the procurement stage of consultant selection were the only ones considered.

None of the documents in the analyzed dataset gave importance to all the project management systems. Documents that focus solely on the schedule, for example, ignore other critical factors such as quality, communication, and risk. Other documents state project comprehension and methodology in general without all the necessary details.

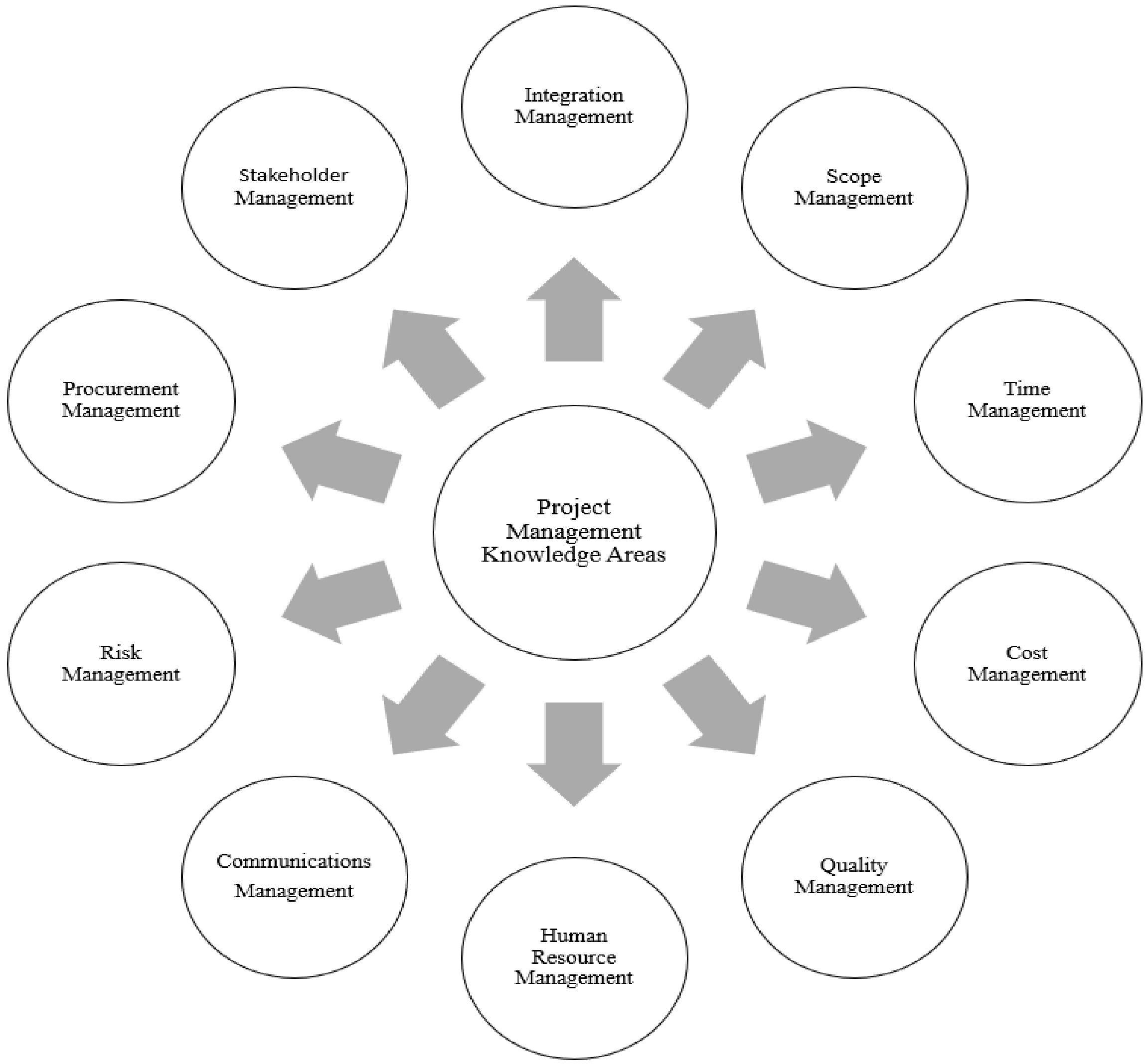

Figure 3.5 Project Management Knowledge Areas, as described by PMBOK Guide (2013)

3.4.3.1 Project Comprehension and Methodology

For the project comprehension and methodology (27%), it comprises sub-criteria related to the overall understanding of the project scope and the proposed methodology, as described in Table 3.1. For example, part of the project scope management knowledge area is covered in this research, since the process of defining the scope involves the development of a detailed description of the project and the product (PMBOK Guide, 2013).

Regarding project communications management, PMBOK Guide (2013) explained that planning communications management is the process that involves the development of a proper communication plan. This plan should be in accordance with the needs and requirements of the stakeholder's information as well as the available organizational assets (e.g., procedures and processes, and knowledge base of the corporate) (PMBOK Guide, 2013).

Two other knowledge areas, which are part of the project comprehension and methodology criterion, are project stakeholder management and risk management. For the former, identifying stakeholders and planning stakeholder management processes (PMBOK Guide, 2013) are both considered in a sub-criterion named stakeholder identification and engagement strategy. Risk management is addressed by identifying different risks and proposing a mitigation approach for each one. A knowledge area like procurement management was not included because it was seen to be suitable for evaluating contractors rather than consultants.

Although safety and environmental factors are not part of the project management knowledge areas and are not considered as evaluation requirements in many of the analyzed documents, they are major factors. Choudhry et al. (2008) stated that health, safety, and environmental management systems are being implemented by several construction companies to eliminate illness, decrease injuries, and provide a safe work environment on sites. The authors also added that the growing importance of the health, safety, and environmental management issues are not only in the daily construction firm's operations but to all people in society as well (Choudhry et al., 2008). Thus, the inclusion of these management systems at the very early stages of a project is crucial not only by contractors but also by consultants. Accordingly, the related safety and environmental sub-criteria should be part of the consultant evaluation process.

The last project comprehension and methodology aspect is related to innovation, creativity, and the consideration of services that can add value to the project and should be necessary for consultant selection. One way to consider this factor is by the inclusion of new techniques that can help in improving design and/or construction services.

3.4.3.2 Quality and Project Controls

The success of project management relies on the accomplishment of quality, time, and cost objectives successfully and how the project management process was carried out (Baccarini, 1999). Hence, project managers devise policies for controlling quality, cost, and schedule to measure the success of a project (Hormozi & Dube, 1999). These three aspects form what is known as the iron triangle (Atkinson, 1999), as illustrated in Figure 3.6. Hence, the three are considered a separate major group of criteria, with a recommended total weight of 20%. In addition, PMBOK Guide (2013) gave importance to each of the three aspects by assigning a separate knowledge area for each one.

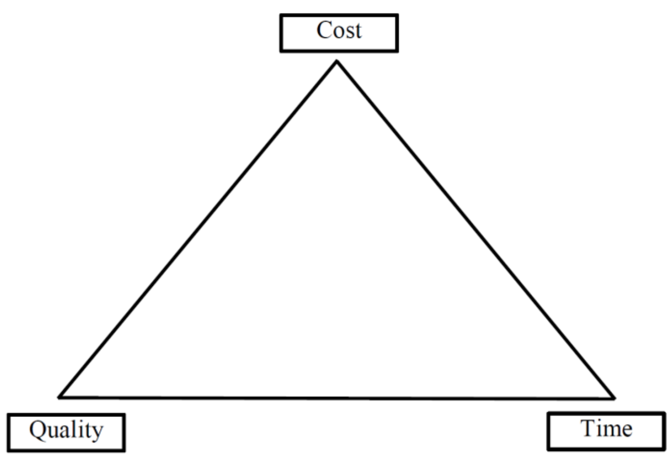

Figure 3.6 The Iron Triangle (Atkinson, 1999)

As described by PMBOK Guide (2013), "Project Quality Management uses policies and procedures to implement, within the project's context, the organization's quality management system." Accordingly, it is necessary that the consultant includes the Quality Assurance/Quality Control (QA/QC) procedure of the firm and how it will be beneficial for that project. In addition, an approach for resolving disputes and/or conflicts is essential as it is deemed to have an impact on the project quality.

The project time management processes take place for managing the timely project completion (PMBOK Guide, 2013). Hence, at the procurement stage, the consultant should be asked to provide a logical task-based schedule as well as an approach to controlling this schedule. For cost control, a cost control approach is required to describe how the consultant costs will be managed throughout the project.

3.4.3.3 Firm Credentials

The consulting firm's experience, expertise, and proven past performance are all significant factors to consider when determining whether the firm can carry out the work. Even if the firm is qualified in terms of the technical aspects such as the proposed project management plans, assessment for the credentials of the firm should be conducted. For instance, the firm needs to provide three relevant detailed project examples, including client references. In addition to these project examples, Table 3.1 includes additional essential sub-criteria, even though they were not often observed in the studied dataset.

3.4.3.4 Project Team Credentials

The credentials of the proposed project team are vital in the choice of a proper consultant for any project, no matter what the characteristics of the project are. According to PMBOK Guide (2013), project human resource management is one of the project management knowledge areas.

To stress the significance of the project manager or leader, it is included as an individual factor with its weight, rather than being included as part of the project team description. Some of the reviewed documents assigned a separate weight for the project leader, with a weight that is higher than that of the entire project team in one of these documents. A project leader is like the "captain of the ship", the greater the leader's technical skills, project management skills, and relevant project experience, the higher the chances of project success.

Key requirements for project team members such as the project organizational chart, level of involvement of team members, professional accreditation, qualifications, and relevant project experience are included in Table 3.1. Sub-consultants must be identified, and their qualifications indicated if they are to take part in the project.

The chemistry between team members, as well as their previous performance as a team, can have a significant influence on the project and predict how well it will perform. As a result, a sub-criterion pertaining to this subject is considered, including relevant project examples demonstrating their previous collaborative work.

Table 3.1 Proposed Criteria, Sub-criteria, and their Weights

Criterion and Criterion Weight %		Sub-criterion	Weight %
Project Comprehension and Methodology 27	Overall Understanding of the Project Scope and Proposed Methodology 10	Proposal quality; proposal detail, presentation, and completeness	2
		Goals, objectives, and tasks comprehension including comprehension of the roles and responsibilities	4
		Detailed specific description of project approach (work plan) including but not limited to: • Integration of cross-disciplinary perspectives • Integration of sub-consultants or specialists' services • Included, excluded, and optional services, and those provided by others	4
	Communications and Stakeholder Management 5	Project communication plan including but not limited to: • Project team communication • Decision documentation strategy for decisions affecting stakeholders and adjacent projects • Status update reporting frequency	3
		Stakeholder identification and engagement strategy	2

Criterion and Criterion Weight %		Sub-criterion	Weight %
	Risk Management 3	Key issues, challenges, and risk identification (classified by quality, safety, schedule, cost, etc.) and proposed mitigation plan for each risk	3
	Safety Management 3	Safety program of the firm and its implementation and effectiveness in this project	3
	Environmental Management 3	Environmental management system of the firm and its implementation and effectiveness in this project, as well as environmental impact and sustainable low impact design considerations	3
	Innovation and Value-Added Services 3	New techniques or technologies that can result in, but are not limited to: • Improve design or construction services • Add value to this project with regard to cost, schedule, or product (e.g., technical, design, and project delivery innovation, as well as creative problem solving)	3
Quality and Project Controls 20	Quality Control 8	QA/QC program of the firm and its implementation and effectiveness in this project	6
		Dispute/conflict resolution methodology	2

Criterion and Criterion Weight %		Sub-criterion	Weight %
	Schedule Control 8	Logical work breakdown structure/task-based schedule that includes all phases, with key stages and critical path(s)	4
		Schedule control approach	4
	Cost Control 4	Cost control approach; detailed plan for managing consultant costs through possible project phases	4
Firm Credentials 25	Firm Qualifications 8	Overview of the organization including firm profile, work history, general qualifications, and achievements' record of the firm (e.g., previous project awards/recognition in the past five years)	4
		Approaches to lessons learned and knowledge sharing inside the firm	4
	Firm Relevant Experience and Past Performance 17	Three relevant projects the firm has completed in the past five years (5% per project) including but not limited to the following: • Description of the project scope, consultant role in the project, project duration, and year completed	15

Criterion and Criterion Weight %	Sub-criterion	Weight %
	• Details about planned vs actual budget and schedule, and reasons for variances • Lessons learned • Innovation in design and/or project delivery • Challenges related to design, construction project delivery and/or methodology, and overcome approaches • Effective communication with clients, stakeholders, as well as the public. • Key project team members' roles in these projects who are proposed for this project • Client references	
	Ability to create long term relationships with clients; one example showing firm experience in developing working relationships with clients in projects of similar nature/type, including but not limited to: • Nature and length of this relationship • A list of completed projects with this client • Client reference	2

Criterion and Criterion Weight %		Sub-criterion	Weight %
Project Team Credentials 28	Project Leader 10	• Technical and project management skills • Experience in similar projects including three relevant project examples to demonstrate successful management of similar projects • Client references • Resume	10
	Project Team 18	Project organizational chart showing roles and responsibilities of key team members. Description of team members includes: • Main team description; a cross-functional team with all the needed disciplines • Main contact point • Resources allocated for communications and stakeholder engagement. • Level of involvement and availability of team members during each project phase • Roles of sub-consultants (if any) and their integration in the team	5
		Education and experience of team members include: • Education, provincial registration/professional accreditation, achievements, skills, and proven qualifications	7

Criterion and Criterion Weight %	Sub-criterion	Weight %
	• Relevant experience of key team members • Sub-consultants (if any) qualifications and relevant experience • Resumes for key team members and sub-consultants	
	• Team previous collaborative projects, with successful completion of at least two relevant projects, and client references	6

3.4.4 Experts Validation of the Conceptual Framework

The proposed criteria breakdown structure shown in Figure 3.4, as well as the detailed criteria and sub-criteria presented in Table 3.1, have been validated by a panel of experts consisting of three industry practitioners. The experts agreed that the proposed criteria breakdown structure is reasonable from the perspective of a consulting engineer.

3.5 Project Templates

A consultant who is the most qualified for one project might not be the best choice for another. As a result, proper consultant selection should consider not only the credentials of the consultant but also the features and requirements of the project. The weights presented in Table 3.1 are recommended for typical projects; however, these weights can be adjusted according to the demands of the project. For eco-friendly projects, for example, a high level of environmental considerations is necessary to minimize any harm to the environment, implying that the weight of the environmental management criterion should be greater than that in typical projects. The same concept can be followed with other criteria such as increasing the weight of the innovation and value-added services criterion for highly innovative projects.

3.6 Pre-evaluation Inquiries

3.6.1 The Underlying Concept Behind the Pre-Evaluation Inquiries

Pre-evaluation inquiries are yes/no questions that will be asked to the decision-maker prior to consultant evaluation to assess whether the consultant is eligible for evaluation or not. The general idea behind these questions is that some of the evaluation criteria are seen to be not suitable as criteria that compare and differentiate between consultants. That is because if some consultants do not fulfill these requirements, there should not be any time or effort spent on their evaluation, as this means that they are not qualified for such an evaluation.

Donabedian (1981) mentioned that “Criteria-Medical care criteria are predetermined elements against which aspects of the quality of medical service may be compared.” By applying the same concept for assessing consultants, medical care criteria shall be the consultant evaluation criteria, and the quality of architectural and engineering services offered by different consultants will be compared instead of that of medical services. Hence, pre-evaluation yes/no questions are points that cannot be considered as criteria but rather conditions with requirements that need to be fulfilled by consultants so that they can be considered for evaluation.

Converting some of the criteria into pre-evaluation inquiries will be beneficial in terms of reducing the number of evaluation criteria. In other words, if there are many criteria involved in evaluating consultants, there is a probability that all consultants will have almost the same overall score in the end. That is because the criteria weights, which have a total equal to 100%, will be distributed over a larger number of criteria if more evaluation criteria are considered. Therefore, the yes/no questions that will be asked before the evaluation will not only reduce the number of consultants that will be evaluated but also will help in decreasing the number of criteria and focusing only on specific ones during evaluation.

3.6.2 Firm Capacity

Capacity was found in three RFP documents as part of the requirements for the capacity of the proponent. "Capacity includes sufficient qualified staff, resources, and expertise," as described in one of these documents. However, the capacity of the consultant should be checked at an earlier stage, not just for the short-listed consultants who reach the detailed evaluation stage. Ng and Skitmore (1999), in their description of some contractor prequalification criteria, stated that the capacity of work means that the “Contractor has too much work at any one time.” Thus, whether the contractor or consultant has a current work overload, they should not be evaluated. The question here is as follows: “does the consultant have sufficient resources allocated for this project?”.

3.6.3 Firm Stability

The strength and stability of the firm were found in an RFP document. Also, the proponent’s financial ability was mentioned as an evaluation factor in two RFP documents. These were discussed by Ng and Skitmore (1999) in the form of two separate contractor prequalification criteria, which are financial stability and firm stability. The authors mentioned that the former indicates the past, present, and future financial status of the contractor, whereas the latter is checked by whether the firm is going through bankruptcy proceedings or not (Ng & Skitmore, 1999). Both criteria are considered to have the same meaning; accordingly, “are the past, present, and future financial status of the consultant stable?” is the question to be asked.

3.6.4 Relevant Experience

There is no doubt that the relevant experience of the consulting firm and the team proposed to work on the project should be considered as evaluation criteria. Whether the firm has been in business for a long time or not, it should not be evaluated if it had not performed similar work before. Therefore, “does the consultant have proven experience in similar nature, scope, and complexity projects?” should be the question asked in advance. In case the answer is yes, and the consultant passes all the other questions, detailed relevant project examples will then be requested as part of the detailed evaluation.

3.6.5 Client-Consultant Relationship

The previous working relationship between the client of the new project and the consultant was included as an evaluation factor in two RFPs. However, if the answer to “is the client-consultant previous working relationship satisfactory?” is no, or there is no chemistry between them, then they should not be working together again.

3.6.6 Referees

Although the consultant will be asked for client references for the relevant project examples that are required as an essential part of the evaluation, the reputation of service to previous clients, in general, should be checked earlier. Reputation was requested in two RFP documents. ACEC-BC (2016), in their description of the proposed evaluation criteria for the request for qualification, asked whether the reference person would work with this consultant again or not. Similarly, Ng and Skitmore (1999) asked the same question as an explanation to a contractor prequalification criterion named reputation. It is, therefore, suggested to contact two clients; the related question is “would the two referees work with the consultant again?”.

3.6.7 Health and Safety Record

The health and safety record, along with the history of claims of the firm, form one evaluation factor, as found in two documents. In addition, five other documents included safety as a pass/fail qualification or prequalification. According to the description provided by Ng and Skitmore (1999), health and safety can be measured through the health and safety record on previous projects as well as the availability of health and safety measures. “Is the health and safety record of the consultant on previous projects acceptable?” is the question to be asked before evaluation. If the consultant becomes qualified for evaluation, by getting a yes in this pre-evaluation question, safety will be further evaluated through the safety management criterion described in Table 3.1.

3.6.8 Claims Record

For the history of claims, “does the consultant have a record of unjustified claims in past projects?” is the question derived from Ng and Skitmore’s (1999) description of the claims and contractual disputes. This was also found in two RFP documents.

3.6.9 Failed Contract

According to Ng and Skitmore (1999), the ten most important contractor prequalification criteria include the failed contract aspect. Using the authors’ explanation to this criterion, the following question is considered for consultants: “has the consultant failed to complete a contract, had a recent termination of a contract by the client, or had withdrawn from a contract prematurely?”, (Ng & Skitmore, 1999). Although it was not found in the analyzed dataset, it is deemed necessary to include it as a yes/no pre-evaluation question.

3.7 Limitations in the Dataset

3.7.1 Absence of a Standard Set of Criteria

From the analysis of the documents, it was found that the main criteria, sub-criteria, and their weights differ from one document to another. There is a lack of “must be used” evaluation criteria. Regarding the technical aspects, one RFP document, for example, did not mention any criteria related to the understanding of the project and its requirements, as well as the methodology for delivering quality projects on schedule and budget. The document just focused on the relevant experience and qualifications of the firm and team, as well as the availability and capability to meet the assigned work requirements.

Another RFP document also focused mainly on the managerial and organizational criteria. It did not ask for the project comprehension and proposed project methodology; however, the schedule and the quality assurance process were the only two technical aspects required as part of the evaluation. Similarly, another document paid more attention to the firm and team credentials, where the schedule was the only technical criterion involved.

Furthermore, a significant criterion like environmental policies was rarely required by the documents. Although its importance varies according to the project characteristics, it should always be involved in the evaluation process, where its weight differs based on the nature of the project. The same issue was encountered with the cost control factor, which was often not considered, although it should be essential to include a described approach for managing and controlling the costs.

It is reasonable to conclude that the described issue was not limited to one or two criteria; it was of a common occurrence. Some documents focus on technical criteria that other documents may overlook, either partially (i.e., only stated as part of a criterion's description) or completely (i.e., not addressed at all). This was the case for several critical criteria, including communications management, stakeholder management, risk management, and innovation and value-added services. In some documents, in the managerial and organizational category, firm credentials were not required, which should not be valid.

The weights of the criteria and sub-criteria had the same issue, with some documents combining various sub-criteria with a single weight for all. It was also discovered that the weight of a single criterion might change considerably from one document to the next. For example, the weight of the schedule factor in a document was more than three times that in another document. In addition, even though the criterion related to the proposed team credentials is essential, it was given zero weight in a document.

3.7.2 Insufficient Descriptions of Criteria

The explanation of the requirements under each criterion, whether through a description or by providing a breakdown (i.e., sub-criteria), was sometimes not enough. The lack of information provided under a criterion increases subjectivity in the evaluation process because the decision-maker, in this case, would not have enough details to be able to assess the consultant properly. For instance, in a document, 40% of the total weight was allocated to a criterion named proposed services and mentioned what was needed for the evaluation of this aspect in just a few words, with no breakdown for the weight. The two requirements under this criterion were providing a basic summary of the services being proposed as well as listing the tasks and timelines. In another example, in a different document, experience and comparable projects were requested without even stating how many project examples are required or what should be covered under those project examples.

Given the criteria's descriptions in some documents, some of the questions would be the following: how would the client, for example, evaluate a total of 30% on detailed work program, project control and scheduling with no weight division? How would the client manage the subjectivity, and would the client be able to assess all proponents equally and fairly without a criterion breakdown or even a sufficient description? Would that mean that the longer and deeper the explanation of the consultant is the better, or would the client prefer if it is shorter and straight to the point?

3.7.3 Combination of Dissimilar Criteria

Merging criteria that should not be added together was another major concern. An example of that was found in a document that included establishing a proper team under the project comprehension and methodology criterion, although there is already another criterion for the proposed project team which asked for a description of the key team members. Similarly, another document had proper resources and fees allocation for the project as a sub-criterion under the project comprehension and methodology, even though the suitability of the project team members could be evaluated through their experience and education, which was already a requirement in the document.

Furthermore, two other documents added the QA/QC procedure of the firm with the project team, which should not be correct as it should be part of the technical requirements under the project comprehension and methodology. Project comprehension and work history were once included together, where the latter should be part of the firm experience and capabilities criterion mentioned in the document. Also, a document combined both project comprehension and firm profile in one criterion. Although this criterion was broken down into two sub-criteria with a separate weight for each one, the name of the criterion should not include both aspects together. Hence, criteria or sub-criteria that do not belong to the same category should not be added together even if they have different weights.

3.7.4 Duplication of Evaluation Requirements

In some situations, an evaluation requirement was repeated under two separate points in the same document. This problem was discovered in two documents for the project comprehension and methodology criterion, with key issues or risk identification falling under both comprehension and methodology. That is incorrect since it was evaluated in two separate weights, resulting in weight misallocation and improper distribution. In a similar manner, a document, which had a specific criterion for the previous work experience within a national park requested the same requirement under another criterion named relevant previous experience and accomplishment.

Two different requirements were repeated in the same document twice. In this document, a minimum of three similar scope contracts, which are active or were completed within the last five years, was requested once under the scope comprehension and work history and another time under the firm experience and capabilities. In addition, a criterion named work coordination asked for the inclusion of any value-added services that can be provided, even though the document had already considered another criterion for the additional features/value-added elements.

Lastly, under the proposal format section in two documents, a detailed methodology for the work as well as the main deliverables for completing the project were mentioned under two different sub-sections (project interpretation and deliverables) in each document.

Chapter 4: Establishment of Evaluation Rules for Measuring Criteria

4.1 Introduction

This research aims to create a decision support system that will help owners in selecting qualified consultants by considering a complete set of evaluation criteria. The objective is to minimize subjectivity and bias during evaluation, as well as increase transparency and consistency in the decision-making process. This is accomplished by objectively measuring the evaluation criteria, which are of qualitative nature, allowing the decision-maker to judge consultants objectively. Simultaneously, the system is designed to be simple to make it easy for different users to utilize.

In the previous chapter, the conceptual model was developed. The model comprises the most significant criteria and sub-criteria needed for consultant evaluation. Four main groups of criteria were identified, with their weights validated by experts. In addition, pre-evaluation inquiries were developed for screening consultants to determine the ones who are eligible for the detailed evaluation. By that, the time and effort of the decision-maker will be saved because only a few consultants who are suitable for the job will be assessed.

The conceptual model was further expanded in this chapter. Literature (research papers and project management books) and the analyzed documents (described in the previous chapter) were used to identify various evaluation rules, as shown in Figure 4.1. These rules were not stated in the literature as rules for measuring consultant evaluation criteria; but rather, they were explained as proper management practices. In addition, the descriptions of criteria, sub-criteria, and evaluation requirements in the analyzed documents were used to determine some of the evaluation rules. The purpose of these rules is to be able to objectively measure different criteria. Different scores were then assigned to the rules based on the relative importance of each rule.

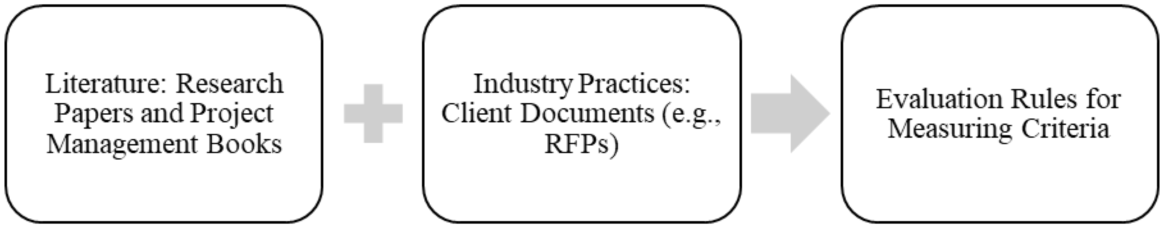

Figure 4.1 Identification of Evaluation Rules for Measuring Criteria

4.2 Description of Evaluation Rules

4.2.1 Overview of Rule-Based Decision-Making

In every area of life, rules and identities serve as a foundation for making decisions, and individuals rely on rules to make judgments and decisions (March, 1994). A complex decision problem can be thought about in a structured manner using rule-based decision-making. This approach can be adopted by entrepreneurs to build opportunity evaluation decisions using rule content, where rule-based thinking can systematically combine rule content in relation to some specific rule criteria to determine opportunity attractiveness (Wood & Williams, 2014). The same concept can therefore be adopted in the evaluation of engineering consultants.

A set of rules was established to solve the problem of subjective evaluation. It is hard to measure criteria like schedule control, cost control, and many others, as they are qualitative. Hence, the most appropriate way of measurement is to define rules for each criterion that will be used by the decision-maker for objective and fair assessment among different consultants. Accordingly, judgments by the decision-maker will more reasonable because assessment will be based on these rules rather than personal opinions, feelings, or assumptions. The real challenge was finding the rules that are appropriate and sufficient for performing a comprehensive evaluation.

4.2.2 Rules for Measurement of Technical Criteria

Technical criteria mainly include the project management systems, such as the plans and methodologies that the firm is going to effectively utilize for the project. These criteria are hard to quantify due to their nature; hence, the use of measurement rules, in that case, is the most suitable solution. The technical criteria category comprises 14 different criteria, with their rules and rules' scores listed in Table 4.1. The total score is 100 for all the rules of each criterion. The names of the technical criteria, as well as the number of rules for each criterion, are shown in Figure 4.2. The average number of rules for the technical criteria is about six, which indicates that checking these rules does not take a long time.

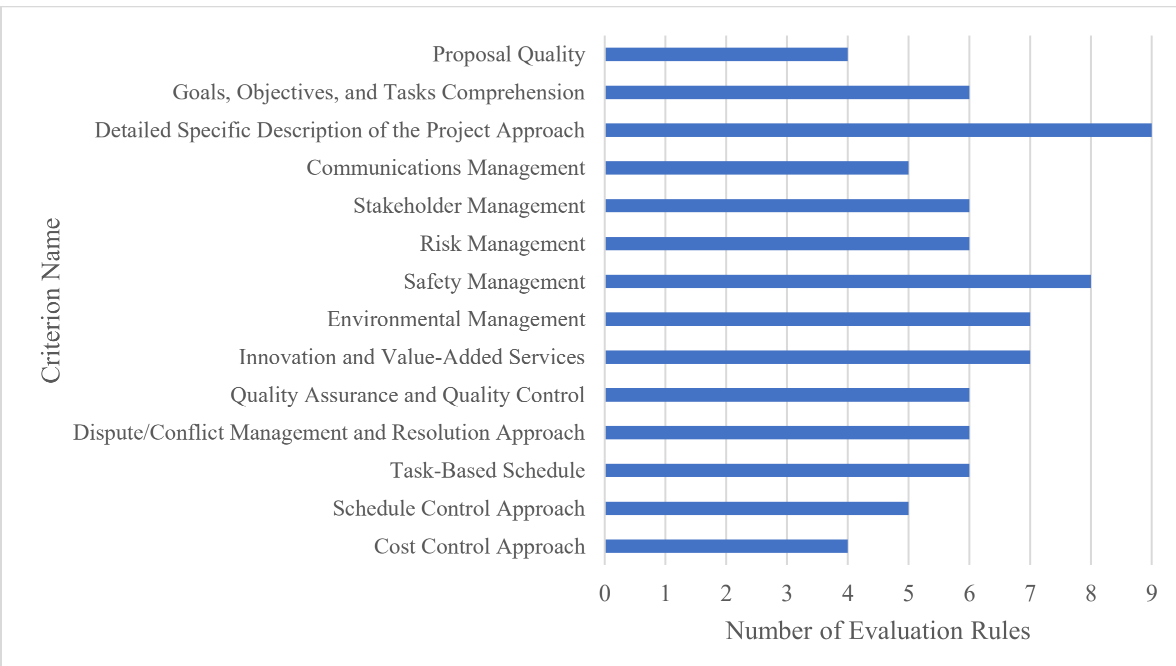

Figure 4.2 Technical Criteria with the Number of Evaluation Rules

4.2.2.1 Proposal Quality (C1)

Four rules form the proposal quality criterion. The proposal should be complete, detailed with all the relevant information, clear in terms of the work description, and is well presented. Equal scores were assigned to the four rules because they are seen to be equally important.

4.2.2.2 Goals, Objectives, and Tasks Comprehension (C2)

C2 comprises six rules. Scope of work comprehension, detailed goals, objectives and deliverables, and roles and responsibilities comprehension are the first three rules. In addition, it is important to mention the consultant's role in construction, such as the review and approval of shop drawings, final walkthroughs, and construction inspections. Showing a deep understanding of the construction QA/QC is also necessary. The remaining rule covers the design vision, which should be presented in the form of an illustrative project comprehension through plans and sketches.

4.2.2.3 Detailed Specific Description of the Project Approach (Work Plan) (C3)

The work plan should be detailed and comprehensive, while at the same time, it must be precise and specific. That is because every project is unique and should therefore have its own separate and specific work plan. Nine rules are needed for a complete assessment of C3. First, the work plan must match the requirements of the RFP. In addition, there should be a basis and logic for the proposed methodology, and the design must be constructible. Since there are always differences between projects, project-specific required approaches should be explained. Furthermore, the integration of cross-disciplinary perspectives is another essential rule of C3. As mentioned by ACEC-BC (2016), all services, even the ones provided by others should be clearly described, as well as the integration of services to be performed by sub-consultants and specialists should be included. The seventh rule focuses on the implementation of the lean principles, which solely accounts for 15% of the total score of C3 due to its importance in assessing and distinguishing between different consultants. Pusca and Northwood (2016) stated that lean is based on five principles and described them as follows:

1. Define value: carried out by the client, where the value is the product that the client will pay for.
2. Identify and map value stream: value stream is the series of processes comprising all actions that are needed for value creation.
3. Create flow via waste removal: flow in the value stream takes place via obstacles' removal such as bottlenecks.
4. Respond to customer pull: switching the system from a push system to a pull system based on the client demand.
5. Strive for perfection.

The consultant is asked to provide information covering all principles except the first one since the first principle is defined by the client, who is usually the owner. As explained by Pusca and Northwood (2016), for the second principle, the main enabler of both effectiveness and efficiency is the processes. Value stream mapping is a technique for quickly visualizing the whole process, determining inefficiencies and bottlenecks, as well as finding areas where processes can be streamlined or enhanced (Pusca & Northwood, 2016).

The last two rules, the eighth and ninth, for measuring C3 are derived from Alberta Infrastructure (n.d.), which they use for consultant performance evaluation. However, some adjustments were made to fit the evaluation at the bidding stage. For the eighth rule, the consultant should present in the work plan how the design at each stage will fulfill basic legislative requirements, codes, and standards related to safety, accessibility, and community needs. The ninth and final rule is concerned with clearly describing the plan for providing a final product that functions, which means a product that is effective, efficient, safe, and easy to operate and maintain (Alberta Infrastructure, n.d.).

4.2.2.4 Communications Management (C4)

The act of conveying information is known as communication (Hollermann et al., 2012). Communications Management consists of five rules. The first three rules are the common ones, which are communication of the project team, decision documentation strategy for decisions affecting stakeholders and adjacent projects, and status update reporting frequency.

The use of technology for communication was not given attention in any of the studied client documents, although it is crucial. According to Rimmington et al. (2015), the evolving nature of construction projects has prompted a shift towards the use of technology as a main method of communication. Lewis (2011) mentioned internet-accessible databases as a communication method used to disseminate information to all project stakeholders. With the COVID-19 pandemic impacting the whole world for over a year now, utilizing technology for communication became crucial. Hence, the use of internet-accessible databases is considered one of the rules needed to assess C4, with 15% of the total score assigned to it.

BIM and Virtual Prototyping have emerged and gained recognition as the foundation for the design, production, and maintenance of many new structures since the beginning of the 21st Century (Baldwin & Bordoli, 2014). BIM is a form of digital documentation. Since relational information is linked to each other and saved in the model, object-oriented construction models like BIM make it much easier to obtain information (Hollermann et al., 2012). Since many significant construction sector clients are increasingly requesting engineering and construction firms to use BIM due to its benefits (Baldwin & Bordoli, 2014), BIM, or any equivalent digital system, was added as an essential rule for measuring C4 and was given the highest score (30%) among all the other communications management rules due to its significance in differentiating between consultants.

There is a link between the last two communications management rules: internet-accessible databases and BIM. The latter is one of the powerful examples of the former. If the consultant uses BIM or an equivalent digital system, which is as strong as BIM, they get the score of both rules.

4.2.2.5 Stakeholder Management (C5)

Client documents that mentioned stakeholder management focused on identifying stakeholders only and generally mentioned the need for a stakeholder engagement strategy. However, stakeholder management entails a much greater set of requirements. According to Vlad (2018), checklists can be used as a supporting tool for stakeholder identification.

Bal et al. (2013) described six steps for an effective stakeholder engagement process, where stakeholder identification accounts for the first step only. The second step is linking stakeholders to a variety of goals, which meet the needs of stakeholders. Prioritization of stakeholders takes place after that. How will the stakeholders' relationship be managed should then be explained, followed by examples of used key performance indicators (KPIs) for measurement of stakeholders' performance (Bal et al., 2013). The sixth step was excluded from this research because it is not applicable at this stage of the evaluation. In view of these five steps, which are all believed to be necessary for measuring C5, they were converted into five rules.

The last rule for C5 is the description of the public engagement plan since public are considered part of the external stakeholders which is necessary to involve.

For the scores, since the first two rules of C3, stakeholder identification and link of stakeholders to different project tasks and objectives, are regarded the most important in comparison to the others, they were given a slightly higher percentage (20% each). Each of the remaining four rules received 15% of the total score.

4.2.2.6 Risk Management (C6)

Risk, being a critical factor, must be looked at carefully. Normally, client documents generally mention the need to identify key issues, challenges and/or risks, with proposed mitigation plans, and few ones ask for risk classification. Risk management can be assessed using six key rules.

According to Baumann et al. (2016), the relevance of risk identification is expanding as the corporate environment becomes more volatile. As part of the risk management process, this step establishes the foundation for all subsequent stages (Baumann et al., 2016). However, none of the documents clarified on what basis will the risk identification part of the consultant submission be assessed, the method that the consultant should apply to identify the risks, and what is considered a clear and sufficient identification of risks and what is not.

Baumann et al. (2016) divided the risk identification methods into two main categories: retrospective risk identification and prospective risk identification. The former is concerned with risks that have occurred in the past and for which knowledge in managing is available are usually best identified through collection methods. Collection methods include A checklist, RIM, SWOT analysis, and interview. For the prospective risk identification, it excludes past data by using creativity tools; therefore, biases encountered while applying collection methods that deal with past data are minimized because past data is purposely withheld from the knowledge base of participants in the risk identification process. Examples of creativity tools include brainstorming, brainwriting, the Delphi technique, and synectics (Baumann et al., 2016). Accordingly, both were considered crucial and were used as two separate rules for the evaluation of the consultant risk management approach. Prospective risk identification was given a slightly higher percentage (20%) than the retrospective one (15%) because identifying risks that have not been encountered before is seen to be more challenging.

In addition to threats, which are considered negative risks, there are also positive risks, which are known as opportunities. Demonstration of opportunities is often missed by clients in the proposal requirements, although they are of great benefit to any project; hence, having this as one of the evaluation rules is necessary.

For risk assessment, some clients request an assessment of the likelihood and impact of the risk. However, it could be rephrased in a different and more detailed way, where the consultant also specifies and clearly explains the risk analysis technique applied (e.g., quantitative).

4.2.2.7 Safety Management (C7)

The focus on managing safety is much higher for contractor evaluation. However, this does not deny the fact that this factor should be given attention for consultants too. Thus, suitable rules for measuring the safety aspect were determined mainly through generally checking construction health and safety elements from the literature and considering whichever points are applicable for consultant evaluation. As mentioned by Choudhry et al. (2008), on-site safety inspections are performed on a daily, weekly, and monthly basis, and on construction sites, joint site walks with consultants are a common occurrence.

The first and basic rule is the description of the safety program, which should be effective and can be implemented for that specific project through both office and site. Findley et al. (2004)

explained that there should be a clear establishment and implementation of the responsibility and accountability of health and safety as well as the establishment of safe work practices for effective management of worksite hazards. In addition, identification of health, safety, and ergonomic hazards through analysis of the worksite should also take place (Findley et al., 2004), which can be considered part of an initial hazard identification process that the consultant can carry out during their site visit. According to Jazayeri and Dadi (2017), for danger control, there should be an initial hazard identification survey.

Employee safety awareness and competency could be improved by safety education and training (Fang & Wu, 2013). As explained by Jazayeri and Dadi (2017), an effective system should be in place for employees to report potentially unsafe issues (e.g., a safety representative, safety committee). Inspections can be conducted at regular intervals, which can be considered a system for identifying dangers (Jazayeri & Dadi, 2017). There should also be emergency response plans to deal with rapidly changing hazards on construction sites (Findley et al., 2004).

4.2.2.8 Environmental Management (C8)

For the environment, and as mentioned in Chapter 3, it was not given attention in the studied client documents although, as explained by Handfield et al. (2001), the greatest possibility to reduce a product's environmental impact is during the product design stages. First, and just like safety management, a comprehensive and effective environmental management system that can be utilized for that specific project should be provided by the consultant. For the remaining rules, a literature review was necessary to determine what is needed to thoroughly evaluate and measure C8.

According to Christini et al. (2004), an environment management system (EMS) of an organization should be designed and implemented with specific objectives, commitments, and methods in mind.

It should also include corrective and preventive actions and emergency plans. In addition, environmental policy should conform with regulations (Christini et al., 2004). By that, three essential rules for measuring the environmental factor were identified.

Hui et al. (2001) explained that the primary purpose of EMS is to reduce environmental impact; this can be achieved through waste reduction, reuse, recycling, and treatment, as well as the use of sustainable resources. Pollution prevention is also required to protect the environment (Hui et al., 2001). Benefits of implementing an EMS include environmental liability minimization and social responsibility commitment (Rumane, 2010). By that, the remaining rules for evaluating C8 were determined.

4.2.2.9 Innovation and Value-Added Services (C9)

Innovation and value-added services require seven rules to be measured. The first five rules were derived from the descriptions used by the industry for evaluating the innovation aspect in the consultant submission. They include the new techniques/technologies that can improve design and construction services, as well as the ones that can add value to the project cost, schedule, and product. These five rules were all considered equally important and were hence, given the same score, which is 10% for each one. The remaining 50% were divided equally onto two separate rules, rules six and seven, which were determined from the literature.

Hidalgo and Albors (2008) stated that it is not always necessary to use the most cutting-edge technology to be innovative; however, it is less about technology and more about a way of thinking and coming up with creative solutions within the firm. In addition, Charyton et al. (2011) clarified the difference between problem solving and problem finding. The former is defined as the capacity to find a solution to a problem or circumstance, whereas the latter is the capacity to identify problems or forecast possible problems that have not yet occurred. The authors added that both are important aspects of an engineer's creativity (Charyton et al., 2011). Accordingly, identification of existing or potential design-related problems and creative problem solving was the sixth rule considered.

The seventh and evaluation rule for C9 is linked to its sixth rule, as it is concerned with the creativity development techniques. Hidalgo and Albors (2008) listed some creativity development techniques which are brainstorming, lateral thinking, mind mapping, TRIZ, and the SCAMPER method. Rumane (2010) explained that TRIZ is short for "theory of inventive problem solving" and is a structured strategy for developing unique ideas and solutions for problem solving that is based on creative thinking. TRIZ, in contrast to brainstorming, strives to develop an algorithmic approach to the invention of new systems and the refining of existing ones. Engineers can use TRIZ to solve problems such as changes in regulations governing the use of specific types of materials (Rumane, 2010).

4.2.2.10 Quality Assurance and Quality Control (C10)

Arditi and Gunaydin (1997) explained that quality assurance entails developing project-specific policies, procedures, standards, guidelines, training, and system required to generate quality. Also, all planned and methodical efforts essential to provide adequate confidence that a structure, system, or component will work successfully and meet project requirements are included in quality assurance (Arditi & Gunaydin, 1997). These were, therefore, the first two rules identified for measuring C10.

The use of a process quality technique such as Six Sigma can also be considered one of the rules for measuring the consultant's QA/QC program. Rumane (2010) indicated that Six Sigma aims to reduce variation in the process and prevent product defects. The variance in a process that has attained Six Sigma capability is negligible in comparison to the specification limits (Rumane, 2010).

For quality control, it represents the specific application of the QA program and related tasks (Arditi & Gunaydin, 1997). Hence, the consultant should properly explain in their submission how the QA program will be effectively implemented for that specific project. Arditi and Gunaydin (1997) clarified that an effective QC decreases the possibility of changes, errors, and omissions, resulting in fewer conflicts and disputes. Therefore, the consultant's plan should explicitly state how they intend to do this.

To improve the quality process, quality control tools can be used (Rumane, 2010). Examples of QC tools include check sheets, histogram, control chart, Pareto analysis, flow chart, cause-and-effect diagram (Rumane, 2010). The consultant should therefore be asked to describe the tool they are going to apply for the project.

Wang (2008) mentioned that in the construction sector, quality inspection and management (QIM) is critical. In addition, QIM should be an intrinsic component of daily work in test laboratories so that the system is maintained on a regular basis and task execution is documented (Wang, 2008). Hence, a rule that is concerned with the frequency of quality inspections was added, through which, for instance, the consultant is required to check that the materials being used conform to the specifications and the ones stated in the design.

4.2.2.11 Dispute/Conflict Management and Resolution Approach (C11)

Proper planning for conflict management from the very beginning helps in the reduction of conflicts and disputes that may occur in the future. Regarding organizational conflict, Jones and

George (2015) mentioned that it occurs when different individuals or groups' aims, interests, or values are incompatible, and those individuals or groups hinder or hinder one another attempts to fulfill their goals. Therefore, the consultant should provide a strategy demonstrating how they are planning to manage such conflicts. An organizational conflict can be an interpersonal, intragroup, or intergroup conflict (Prause & Mujtaba, 2015). Conflict within the same group is known as intragroup conflict, whereas intergroup conflict is the conflict that occurs with other groups (Jones & George, 2015).

Strategy for the management of diverse workplace challenges is another important aspect. As stated by Prause and Mujtaba (2015), the term "workplace diversity" refers to an emphasis on the differences among employees. A diverse workplace, if appropriately managed and organized, can be a positive force in a business, providing fruitful collaboration, creativity, greater recruitment opportunities, and higher productivity (Prause & Mujtaba, 2015).

Diversity awareness and job training on diversity are also considered in measuring C11. According to Prause and Mujtaba (2015), individuals with accurate perceptions and understanding of diversity can change their behaviors and attitudes, resulting in increased diversity skills, improved interaction, and a healthier work environment. Therefore, managers should work on diversity awareness every day and encourage employees to rethink their perceptions of the notion (Prause & Mujtaba, 2015). In addition, conflict management training should take place, and so it was used as one of the fundamental rules for evaluating C11. Prause and Mujtaba (2015) highlighted that diversity education, conflict management training, and the development of innovative thinking can help modern businesses compete more effectively in the market and can be a critical step in building advanced companies with strong human resources.

The last two evaluation rules for C11 are concerned with the previously managed conflicts. The consultant should provide at least two examples of previously managed conflicts as well as a description of the conflict solving technique used. If the conflict was solved through a negotiation process, for example, the consultant should describe the negotiation style adopted (e.g., cooperative, competitive). As described by Jeong (2009), a multi-step conflict resolution method tries to identify different sorts of controversial issues, uncover their underlying causes, and devise a strategy for resolving them. This should be provided by the consultant in their explanation of previously managed conflicts' examples.

4.2.2.12 Task-Based Schedule (C12)

C12 comprises six evaluation rules, where four of them were extracted from the studied client documents. The first rule is concerned with providing a logical work breakdown structure for the schedule, with the schedule broken down into different levels until reaching the activity level. In addition, the Gantt chart must be included with the schedule. All key stages and phases should be presented in the schedule, and the duration of activities, as well as the critical path, must be logical. For the activity total and free floats, both must be realistic. Except for the logical work breakdown structure, which received 25% of the overall score owing to its criticality, other rules were given equal scores (15%).

4.2.2.13 Schedule Control Approach (C13)

Microsoft Project and Primavera are two of the scheduling software examples being used (Lewis, 2011). This software should also be the one used for progress updates and the generation of reports. Additionally, the consultant is asked to mention the planned frequency of the progress updates.

A plan for managing schedule changes through different phases is needed. This plan should be detailed and well described. The method used for monitoring progress should also be properly explained. For example, earned value analysis (EVA) is a method used for that purpose (Baldwin & Bordoli, 2014). According to the same authors, many people believe that EVA is the best method for evaluating progress because it considers time, cost, and scope. At all levels, EVA is adaptable and capable of generating timely information (Baldwin & Bordoli, 2014).

4.2.2.14 Cost Control Approach (C14)

Without any sort of management cost and control system, no program or project can be effectively structured and managed (Kerzner, 2017). Therefore, the consultant should provide a plan for managing costs through different phases, which should be thorough and clearly explained.

A true evaluation of performance must consider not only improvement through time but also progress in terms of cost and value (Baldwin & Bordoli, 2014). As explained for the schedule control approach, EVA is concerned with not only time but cost as well. Thus, EVA, or equivalent, is added as an essential rule for measuring C14.

The last rule for proper measurement of the cost control approach is the use of a proper cost control software such as Oracle or the SAP system. Therefore, the consultant should specify the software they are going to utilize for this purpose.

Table 4.1 Evaluation Rules for Measuring the Technical Criteria and their Corresponding Scores

S.N.	Criterion	Evaluation Rule	Score
C1	Proposal Quality	1.1 Complete Proposal	25
		1.2 Detailed proposal with all the relevant information	25
		1.3 Clear proposal in terms of work description	25
		1.4 Well-presented proposal	25
C2	Goals, Objectives, and Tasks Comprehension	2.1 Scope of work comprehension	20
		2.2 Detailed goals, objectives, and deliverables	20
		2.3 Roles and responsibilities comprehension	20
		2.4 Inclusion of the consultant's role in construction (e.g., shop drawing review and approval, final walkthroughs, construction inspections)	20
		2.5 Deep understanding of the construction QA/QC	10
		2.6 Design vision - Illustrative project comprehension (e.g., plans, sketches)	10
C3	Detailed Specific Description of Project Approach (Work Plan)	3.1 Work Plan matches the RFP requirements	10
		3.2 Methodology rationale and constructability of design	10
		3.3 Inclusion of project specific required approaches	10
		3.4 Description of included, excluded and optional services, and those provided by others	10
		3.5 Integration of cross-disciplinary perspectives	10
		3.6 Integration of sub-consultants and/or specialists' services	10

S.N.	Criterion	Evaluation Rule	Score
		3.7 Implementation of lean principles (e.g., identify and map value stream, create flow via waste removal, respond to customer pull, and strive for perfection)	15
		3.8 Design at each stage fulfills basic legislative requirements, codes, and standards related to safety, accessibility, and community needs	15
		3.9 Clear plan for providing a final product that functions; a product that is effective, efficient, convenient, safe, and easy to operate and maintain	10
C4	Communications Management (Project Communication Plan)	4.1 Project team communication	25
		4.2 Decision documentation strategy for decisions affecting stakeholders and adjacent projects	25
		4.3 Status update reporting frequency	5
		4.4 The use of Internet accessible databases	15
		4.5 The use of BIM or any equivalent digital system	30
C5	Stakeholder Management	5.1 Identification of all key stakeholders (e.g., the use of checklists)	20
		5.2 Link of stakeholders to different project tasks and objectives (meet the stakeholders' needs and interests)	20
		5.3 Prioritization of stakeholders	15
		5.4 Management of stakeholders (how will their relationships be managed?)	15
		5.5 Measurement of stakeholders' performance (examples of the used KPIs)	15

S.N.	Criterion	Evaluation Rule	Score
		5.6 Description of the public engagement plan	15
C6	Risk Management	6.1 Retrospective risk identification: risks that have occurred in the past and for which knowledge in managing is available (e.g., the use of checklists, RIM, SWOT analysis, interview)	15
		6.2 Prospective risk identification, which excludes past data (the use of creativity tools: (e.g., brainstorming, brainwriting, the Delphi technique, synectics)	20
		6.3 Classification of risks (e.g., quality, safety, schedule, cost, etc.)	10
		6.4 Demonstration of potential opportunities, not just threats	15
		6.5 Description of the risk analysis technique (e.g., quantitative) and assessment of the likelihood and impact of each risk	20
		6.6 Proposed mitigation/response plan for each risk	20
C7	Safety Management	7.1 Comprehensive safety program that is effective and can be implemented for this specific project through office and site	20
		7.2 Clear establishment and implementation of the responsibility and accountability of health and safety	15
		7.3 An effective system in place for employees to report potentially unsafe issues (e.g., a safety representative or safety committee)	15

S.N.	Criterion	Evaluation Rule	Score
		7.4 Identification of health, safety, and ergonomic hazards through analysis of the worksite (initial hazard identification survey)	15
		7.5 Establishment of safe work practices for effective management of worksite hazards	10
		7.6 Frequency of worksite inspections (which can be a system for hazard identification)	5
		7.7 Emergency response plans	15
		7.8 Safety education and training (for improvement of the employees' safety awareness)	5
C8	Environmental Management	8.1 Comprehensive environmental management system of the firm that is effective and can be implemented in this specific project	20
		8.2 Regulatory compliance of environmental policy	15
		8.3 Defined goals, commitments, and methods for meeting environmental requirements	10
		8.4 Corrective and preventive actions, and emergency plans	10
		8.5 Sustainable low impact design considerations that have minimal effect on the environment including reduction, reuse, recycle and treatment of waste, use of sustainable resources, and pollution prevention	20
		8.6 Environmental management system describes how the environmental liability is minimized	10
		8.7 Environmental management system describes commitment to social responsibility	15

S.N.	Criterion	Evaluation Rule	Score
C9	Innovation and Value-Added Services	9.1 New techniques or technologies that can improve design (e.g., technical innovation, design innovation)	10
		9.2 New techniques or technologies that can improve construction services (e.g., project delivery innovation)	10
		9.3 New techniques or technologies that can add value to this project with regard to cost	10
		9.4 New techniques or technologies that can add value to this project with regard to schedule	10
		9.5 New techniques or technologies that can add value to this project with regard to the product	10
		9.6 Identification of existing or potential design related problems, and creative problem solving	25
		9.7 Discussion on the implementation of creativity development techniques (e.g., brainstorming, lateral thinking, mind mapping, TRIZ, the SCAMPER method)	25
C10	Quality Assurance and Quality Control	10.1 QA: Development of project-specific policies, procedures, standards, guidelines, training, and system required to produce quality	25
		10.2 Inclusion of all planned and methodical actions in the quality assurance program, which are essential to provide adequate confidence that a structure, system, or component will work successfully and meet project requirements	20
		10.3 Use of a process quality technique (e.g., Six Sigma technique)	15

S.N.	Criterion	Evaluation Rule	Score
		10.4 Clear description of effective implementation of QA program and related tasks (which represent the QC), and how the QC plan can decrease the possibility of changes, errors, and omissions	20
		10.5 Description of the QC tool that is going to be applied for this project (e.g., check sheets, histogram, control chart, Pareto analysis, flow chart, cause-and-effect diagram)	15
		10.6 Frequency of quality inspections, site monitoring/reviews and reporting	5
C11	Dispute/Conflict Management and Resolution Approach	11.1 Strategy to management of organizational conflict (interpersonal conflict, intragroup conflict, and intergroup conflict)	20
		11.2 Strategy to management of diverse workplace challenges	15
		11.3 Diversity awareness and job training on diversity	15
		11.4 Conflict management training	15
		11.5 At least two examples of previously managed conflicts, with description of the conflict solving technique (e.g., negotiation style, meditation)	20
		11.6 The examples of previously managed conflicts cover the following: identifying different sorts of controversial issues, discovering their underlying causes, and devising a strategy to remove them	15
C12	Tasked-Based Schedule	12.1 Logical work breakdown structure (task-based schedule)	25
		12.2 Inclusion of Gantt chart	15

S.N.	Criterion	Evaluation Rule	Score
		12.3 Logical duration of activities	15
		12.4 Inclusion of all key stages/milestones and phases in the schedule	15
		12.5 Inclusion of logical critical path(s)	15
		12.6 Logical total and free floats of activities	15
C13	Schedule Control Approach	13.1 Schedule developed using a suitable scheduling software (e.g., Primavera, MS Project)	30
		13.2 The mentioned scheduling software will be used for progress updates, reports generations, etc., with mention of the frequency of those updates	10
		13.3 Plan for managing schedule changes through different phases	15
		13.4 Proper description and sufficient detail of the schedule management plan	15
		13.5 Use of Earned Value Analysis or equivalent, with proper description	30
C14	Cost Control Approach	14.1 Plan for managing consultant costs through different phases	20
		14.2 Proper description and sufficient detail of the cost management plan	20
		14.3 Use of Earned Value Analysis or equivalent, with proper description	30
		14.4 Use of a cost control software (e.g., Oracle, the SAP system), with proper description	30

4.2.3 Rules for Measurement of Managerial and Organizational Criteria

The managerial and organizational criteria are concerned with the firm and team credentials. Most of the rules were extracted from the descriptions of criteria and sub-criteria provided in the analyzed client documents. Some further details were needed to have a comprehensive evaluation; hence, additional rules were obtained from the literature. The managerial and organizational criteria category comprises eight different criteria, where one of these criteria (three relevant project examples) is divided into three, bringing them to a total of 10 criteria. All evaluation rules used to measure the criteria under this category, with their corresponding scores, are listed in Table 4.2. The total score of all the rules forming each criterion is 100. The names of the different managerial and organizational criteria, as well as the number of rules for each criterion, are shown in Figure 4.3. Checking the consultant's fulfillment to the managerial and organizational criteria requirements is not time-consuming since the average number of rules for this category is six.

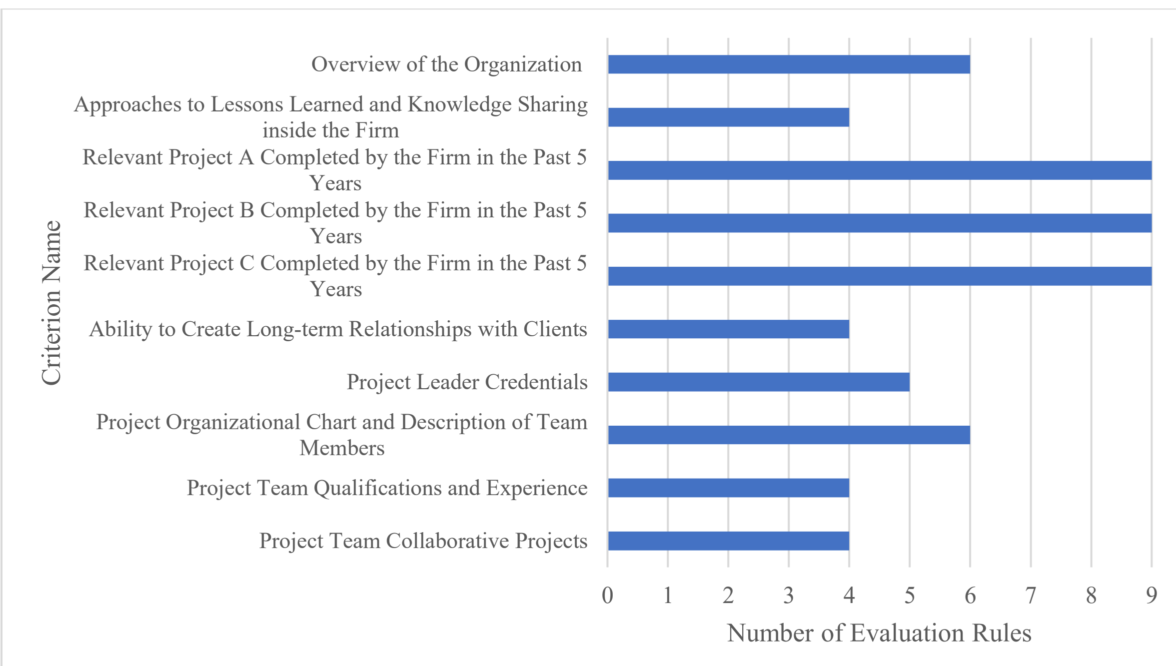

Figure 4.3 Managerial and Organizational Criteria with the Number of Evaluation Rules

4.2.3.1 Overview of the Organization (C15)

C15 comprises six rules which are mainly needed to provide a summary of the previous work and accomplishments of the firm. In general, the firm profile should be acceptable in terms of the previous projects completed or in progress, and the work history should be properly described. The firm's general qualifications should also be clearly explained.

Regarding previous project awards and/or recognition, the general ones received in the past five years should be described, in addition to the ones for projects of similar scope and nature to that specific project. The last rule is concerned with any remarkable certifications in aspects like quality, environmental, or others. For the ISO, for example, Rumane (2010) clarified that the term "certification" in the context of ISO 9000 or ISO 14000 refers to the issuance of written assurance (the certificate) by an independent, external entity that has audited the management system of an organization and verified that it complies with the standard's requirements.

4.2.3.2 Approaches to Lessons Learned and Knowledge Sharing inside the Firm (C16)

The consultant is asked to provide a general description of the firm's lessons learned and knowledge sharing approach. It is also important to demonstrate how the lessons learned from previous projects are being implemented in new projects, with a sufficient and detailed description.

The last rule, which accounts for over one-third of C16's score due to its importance, focuses on the knowledge sharing being ICT supported. As stated by Charrel and Galarreta (2007), "If knowledge sharing is ICT supported, for instance using Intranet as a medium, then knowledge storage is a natural part of the knowledge sharing task".

4.2.3.3 Three Relevant Project the Firm has Completed in the Past Five Years (C17)

C17 is divided into three sub-criteria, one for each project (Project A, Project B, and Project C). Each project includes the exact same rules, but they are separated as each one needs to be evaluated individually in detail. Hence, the rules explained under this section are repeated three times.

The rules used to evaluate C17 are similar to some of the points listed under the "Firm Relevant Experience and Past Performance" criterion in Table 3.1. However, a new last rule was added in this chapter, which is concerned with the identification of quality improvement opportunities (Rumane, 2010) found in previous projects that the consultant has worked on.

4.2.3.4 Ability to Create Long-Term Relationships with Clients (C18)

For C18, the consultant is required to provide one project example demonstrating their ability to build a long-term relationship with a client. In addition, the consultant is asked to list all projects, relevant and non-relevant to that specific project, that they have worked on with that client. All the rules were considered equally important, and so were given the same score (25%).

4.2.3.5 Project Leader Credentials (C19)

For the project leader, which includes five essential rules, the descriptions found in the analyzed client documents were considered sufficient for the proper measurement of C18. Strong technical and project management skills are critical in determining the project leader's capabilities to manage the project; thus, this rule received a quarter of C19's score.

4.2.3.6 Project Organizational Chart and Description of Team Members (C20)

Similar to C19, the rules for measuring the project organizational chart and team members' descriptions were derived from the studied client documents. One additional rule, used by Alberta Infrastructure (n.d.) as an aspect for evaluating the performance of consultants, was considered.

This point is concerned with describing the credentials of the contract administrator who will be assigned to that project.

4.2.3.7 Project Team Qualifications and Experience (C21)

For the project team qualifications and experience, in addition to the points mentioned in Chapter 3, a separate rule was reserved for the description of specific requirements for the project team members such as the need for a landscaping expert or an environmental specialist.

4.2.3.8 Project Team Collaborative Projects (C22)

The last criterion is related to the projects that the key team members have previously worked on together. It comprises four evaluation rules. The first rule, which covers the description of previous collaborative projects, should include projects of similar nature and scope to that new project; therefore, this rule received 30% of the score due to its significance. The second and third rules are both concerned with the successful completion of relevant projects, one project for each rule, and so, were given equal scores. In the last rule, the consultant is asked to provide client references for those projects.

Table 4.2 Evaluation Rules for Measuring the Managerial and Organizational Criteria and their Corresponding Scores

S.N.	Criterion	Evaluation Rule	Score
C15	Overview of the Organization	15.1 Satisfactory firm profile	15
		15.2 Proper description of firm's work history	15
		15.3 Good and sufficient explanation of firm's general qualifications	15
		15.4 Previous general project awards/recognition in the past five years	15
		15.5 Project awards for projects of similar scope and nature to this specific project	20
		15.6 Any remarkable certifications in quality, environmental, or any other aspects (e.g., ISO)	20
C16	Approaches to Lessons Learned and Knowledge Sharing inside the Firm	16.1 General description of the lessons learned and knowledge sharing approach of the firm	25
		16.2 Description of how the lessons learned from previous projects are implemented in new projects	25
		16.3 Detailed and sufficient description provided in the previous point (16.2)	15
		16.4 Knowledge sharing is ICT supported (e.g., the use of Intranet)	35
C17	Three Relevant Projects the Firm has Completed in the Past Five Years (The Provided Rules for C17 are	17.1 Description of the project scope, consultant role in the project, project duration, and year completed	5
		17.2 Details about planned vs actual budget and schedule, and reasons for variances	15
		17.3 Effective communication with clients, stakeholders as well as the public	10
		17.4 Challenges related to design, construction project delivery and/or methodology, and overcome approaches	10

S.N.	Criterion	Evaluation Rule	Score
	Repeated for Each Project)	17.5 Lessons learned	10
		17.6 Key project team members' roles in those projects who are proposed for this project	10
		17.7 Innovation in design and/or project delivery, and creative problem solving	10
		17.8 Identification of quality improvement opportunities	10
		17.9 Client references	20
C18	Ability to Create Long-Term Relationships with Clients	18.1 A project example with that client; a project which is of similar nature and scope to this specific project	25
		18.2 Description of the nature and length of that working relationship	25
		18.3 A list of projects completed with that client (including relevant and non-relevant projects)	25
		18.4 Client reference	25
C19	Project Leader Credentials	19.1 Description of technical and project management skills	25
		19.2 Description of experience in similar projects	20
		19.3 The described experience includes at least three relevant project examples demonstrating successful management of similar projects	20
		19.4 Resume	15
		19.5 Client references for three relevant project examples	20

S.N.	**Criterion**	**Evaluation Rule**	**Score**
C20	Project Organizational Chart and Description of Team Members	20.1 Project organizational chart showing roles and responsibilities of key team members and sub-consultants (if any)	25
		20.2 Main team description showing a cross-functional team with all the needed disciplines	25
		20.3 Specification of main contact point	5
		20.4 Description of resources allocated for communications and stakeholder engagement	15
		20.5 Description of level of involvement and availability of team members during each project phase	15
		20.6 Description of the contractor administrator who will be assigned to this project (must be proficient)	15
C21	Project Team Qualifications and Experience	21.1 Description of relevant experience of key team members and sub-consultants (if any)	30
		21.2 Description of education, provincial registration/professional accreditation, achievements, skills, and proven qualifications of key team members and sub-consultants (if any)	30
		21.3 Any specific requirements for key team members (e.g., landscaping expert, environmental specialist)	20
		21.4 Resumes of key team members and sub-consultants (if any)	20

S.N.	Criterion	Evaluation Rule	Score
C22	Project Team Collaborative Projects	22.1 The described collaborative projects are of similar nature and scope to this specific project	30
		22.2 Successful completion of one relevant project	25
		22.3 Successful completion of another relevant project	25
		22.4 Client references for team previous collaborative projects	20

Chapter 5: Development of a Computerized Analytical Model for Consultant Evaluation and Ranking

5.1 Introduction

The evaluation and ranking of consultants must occur reliably and fairly, with the least possible subjective judgments. The system through which this process will take place must be comprehensive, encompassing all the necessary aspects.

In the preceding chapters, Chapters 3 and 4, a thorough theoretical framework for consultant evaluation and selection was created. A standard set of evaluation criteria and sub-criteria was first identified, and pre-evaluation inquiries were developed. Evaluation rules were then gathered from research papers, project management books, and industry practices to objectively measure the different criteria.

In this chapter, an automated analytical model, which implements the fuzzy TOPSIS technique, is developed using the Python (PyCharm) programming language. Figure 5.1 depicts a summary of the entire process carried out by the model. The output of the model is the ranking of different consultants.

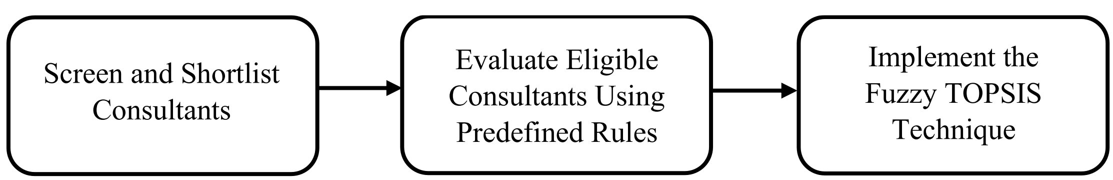

Figure 5.1 Summary of the Automated Three-Step Consultant Evaluation and Ranking Process

5.2 Screening and Shortlisting of Consultants

Consultants are screened using the pre-evaluation yes/no questions described in Chapter 3 during the preliminary stage of the evaluation and ranking process. This phase is required to limit the number of consultants by excluding those who are not eligible for a comprehensive review of their qualifications, allowing the decision-maker to concentrate on specific consultants during the detailed evaluation stage. The screening process of the developed decision support system is presented in Figure 5.2. At the beginning of the process, the decision-maker is required to specify the criteria weights according to some project characteristics that they should enter. The decision-maker will also be provided with the recommended criteria weights detailed in Chapter 3. The output of the flow chart described in this figure, which is determining the eligible consultants, is the input for the next step of the process.

5.3 Detailed Evaluation Using Predefined Rules

During this stage, eligible consultants who pass the screening process are evaluated, as shown in Figure 5.3. Each criterion comprises a certain number of evaluation rules, as described in Chapter 4. The decision-maker is required to check those rules and has three choices: yes, no, or not applicable. The answer should be "yes" if the rule is applicable and its requirements are fulfilled by the consultant in their proposal submission, "no" if the rule is applicable and the submission does not include the rule requirements, and "na" if the requirements of the rule are not applicable for that project. According to the answers provided by the decision-maker to the evaluation rules, the total score for each criterion will be automatically calculated, which will be converted to a linguistic rating (low, medium, or high). The fuzzy TOPSIS approach will then be implemented.

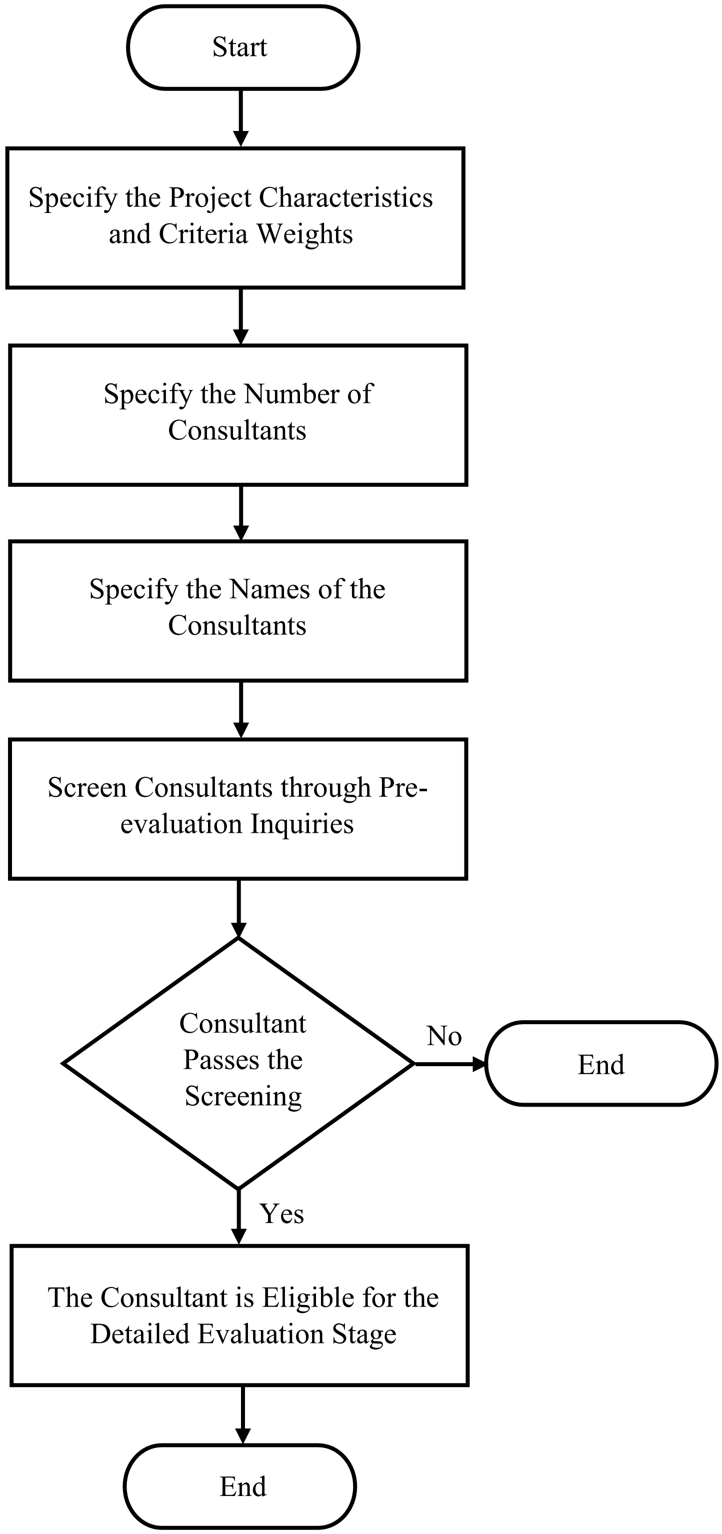

Figure 5.2 Automated Process for Screening and Shortlisting of Consultants

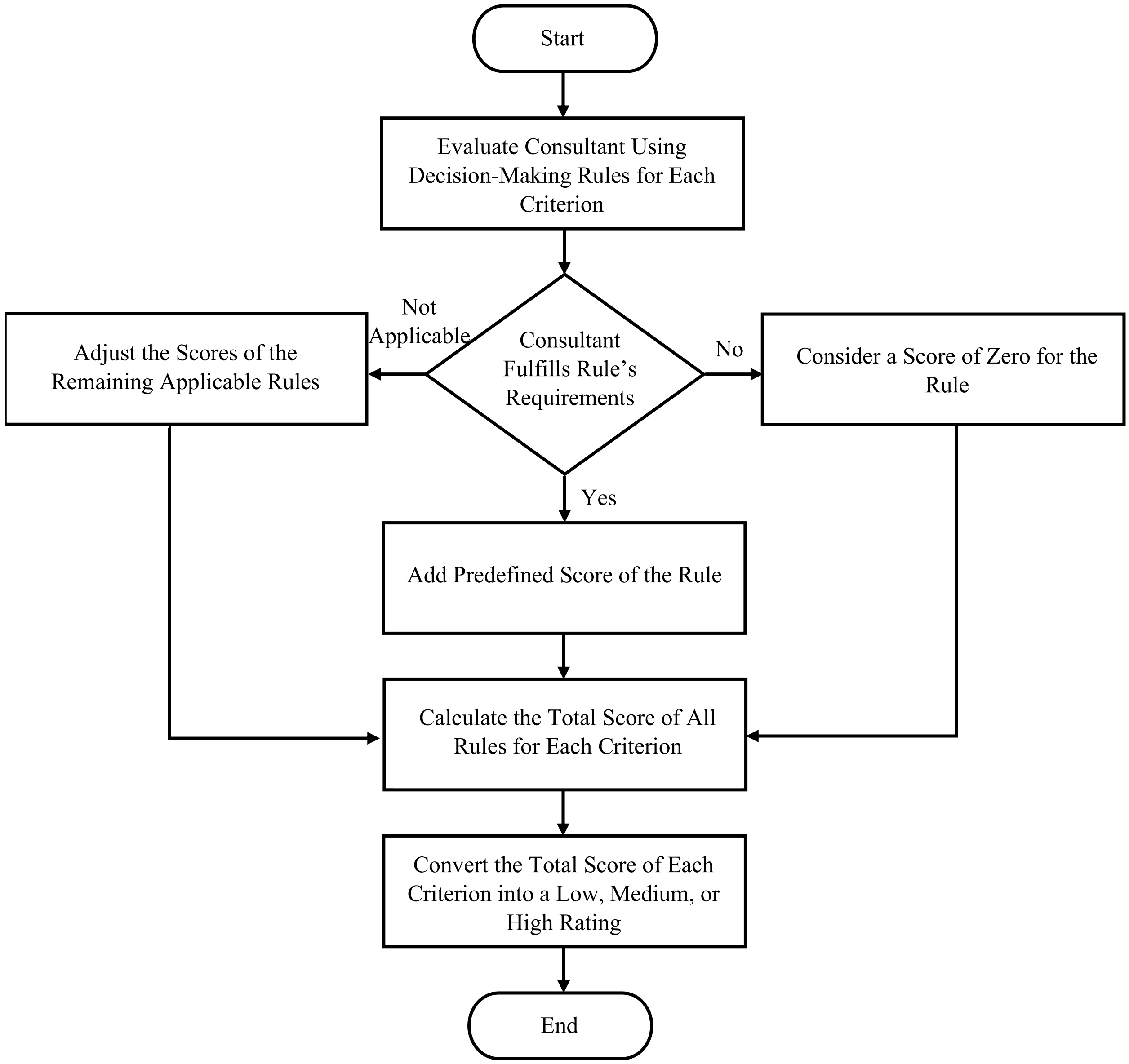

Figure 5.3 Automated Process for Detailed Evaluation of Consultants

Yes and no answers to the evaluation rules are needed if the rules are applicable. However, since some of the rules may not be applicable for some projects, especially small-sized projects, the decision-maker has the not applicable option for the rule. In this case, the scores of the remaining rules for that criterion will be adjusted accordingly.

5.4 Implementation of the Fuzzy TOPSIS Technique

The fuzzy TOPSIS technique is utilized after all eligible consultants have undergone a thorough evaluation, with the results of this evaluation (low, medium, and high ratings) serving as input to the fuzzy TOPSIS model. Figure 5.4 depicts the events that occur in the fuzzy TOPSIS model. The steps mentioned in this figure will be detailed in the next sections.

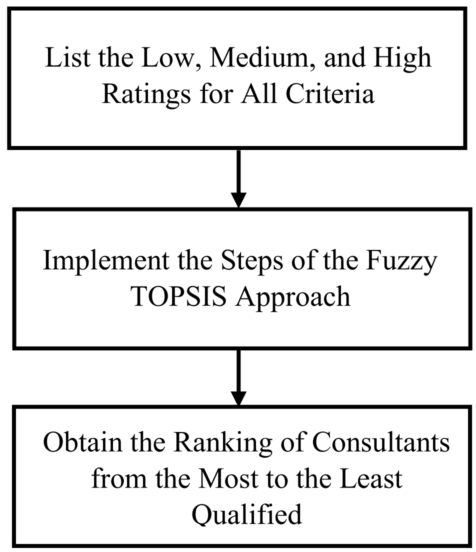

Figure 5.4 Summary of the Automated Consultant Ranking Process

5.4.1 Overview of the Fuzzy TOPSIS Technique

Fuzzy TOPSIS is determined to be the best-suited approach for dealing with the multi-criteria decision-making problem addressed in this research. The fuzzy component of the method, as indicated in Figure 5.5, deals with linguistic variables by transforming them into fuzzy numbers. Following that, TOPSIS does certain mathematical computations to generate the ranking of different consultants.

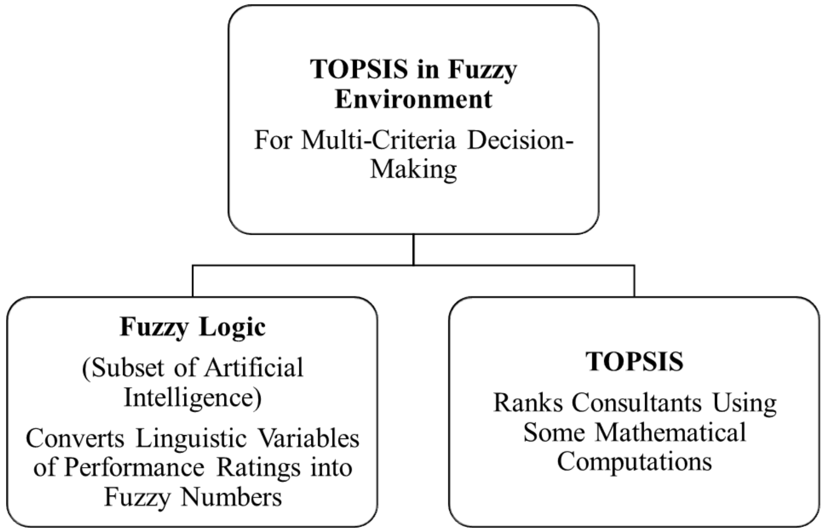

Figure 5.5 Components of the Fuzzy TOPSIS Technique

5.4.2 Utilization of the Fuzzy Logic Component of the Fuzzy TOPSIS Technique

Normally, the decision-maker provides an evaluation in the form of a linguistic term (e.g., low, medium, high) in previous implementations of the fuzzy TOPSIS technique. What is different and new in this research is that the decision-maker reviews the rules for each criterion, then responds to each rule with a yes (consultant submission covers the rule requirements), no (consultant submission does not cover the rule requirements), or not applicable (the rule is not relevant for that project) response. The developed model will automatically calculate the overall score for each criterion (out of 100) after receiving the responses to the evaluation rules. Using the Python programming language, this score will be transformed to a low, medium, or high rating. As a result, subjectivity in the consultant evaluation process is minimized, and consistency is improved because the answers to the evaluation rules are what determine the performance ratings.

Roberts (1986) explained that fuzzy set theory is an extension of classical set theory in which elements of a set have membership grades ranging from zero to one [0,1], with zero indicating non-membership and one indicating full membership. There are operators, relations, and mappings appropriate for these fuzzy sets, just as there are for classical sets (Roberts, 1986).

In this research, trapezoidal fuzzy numbers are used. Trapezoidal fuzzy numbers are fuzzy numbers with a trapezoid-shaped membership function (Kuchta, 2001). The trapezoidal curve is defined as a function of a vector, x, and four scalar parameters, a, b, c, and d, as shown in Equation 5.1 (Princy & Dhenakaran, 2016), where $\mu(x)$ represents the membership function.

$$\mu_A(x) = \begin{cases} 0, & (x < a) \; or \; (x > d) \\ \dfrac{x-a}{b-a}, & (a \le x \le b) \\ 1, & (b \le x \le c) \\ \dfrac{d-x}{d-c}, & (c \le x \le d) \end{cases} \tag{5.1}$$

A lower limit a, an upper limit d, a lower support limit b, and an upper support limit c define the parameters, where a < b < c < d, as illustrated in Figure 5.6 (Princy & Dhenakaran, 2016).

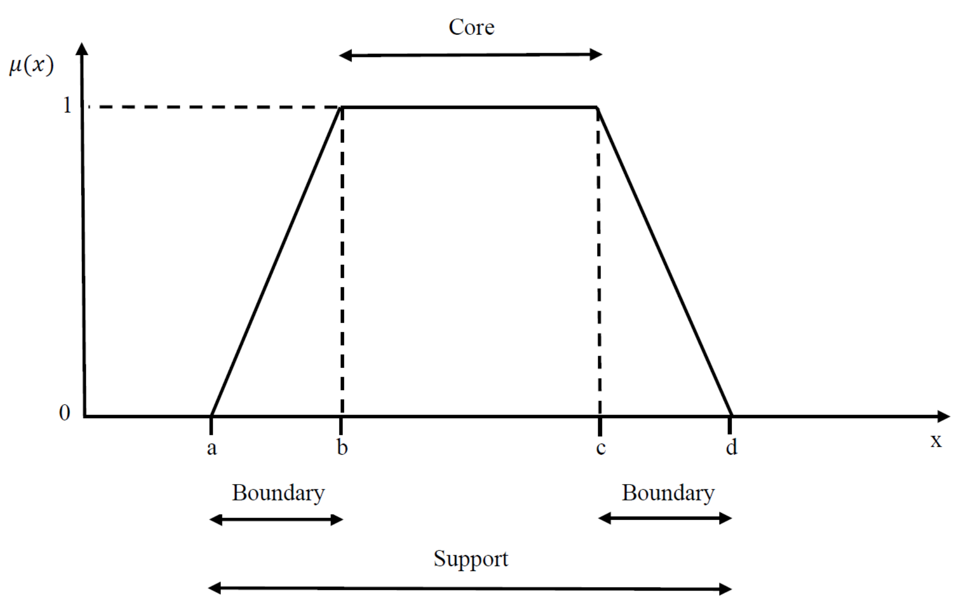

Figure 5.6 Trapezoidal Membership Function (Princy & Dhenakaran, 2016)

Each linguistic variable on the three-point scale employed (low, medium, and high) includes a range of scores, as shown in Table 5.1, which was determined after analyzing the evaluation criteria and establishing a suitable range for each rating. The aim was also to maintain each rating's range as close as possible to the standard grading system. For example, the high rating spans from 80 to 100, which corresponds to the excellent grades (A+, A, and A-) in the commonly used grading system. If the user needs to change any of the recommended ranges of scores for the linguistic ratings or modify the scores assigned to the evaluation rules, the system administrator can make the necessary changes.

Table 5.1 Linguistic Variables for the Ratings

Linguistic Variable	**Trapezoidal Fuzzy Number**
Low	(0,0,40,50)
Medium	(45,50,80,85)
High	(80,90,100,100)

Even though triangular fuzzy numbers have been used in many publications, trapezoidal fuzzy numbers were found to be more suited to the problem under consideration. That is because full membership is gained at the apex, which is represented by only one number, in the case of triangular fuzzy numbers. However, it appears to be more reasonable that for the consultant evaluation problem, a membership function of one (full membership) occurs at more than one value, each of which represents a score. Accordingly, trapezoidal fuzzy numbers were employed, where the maximum value is represented by a range of values rather than a single value, as illustrated in Figure 5.7.

The trapezoidal fuzzy numbers, shown in Figure 5.7, reflect the range of scores for each linguistic variable. The low rating is defined as (∞, ∞, c, d), the medium rating is represented as (a, b, c, d), and (a, b, ∞, ∞) denotes the high rating. According to Kuchta (2001), the shape functions (∞, ∞, c, d) and (a, b, ∞, ∞) of fuzzy numbers are special types of trapezoidal fuzzy numbers

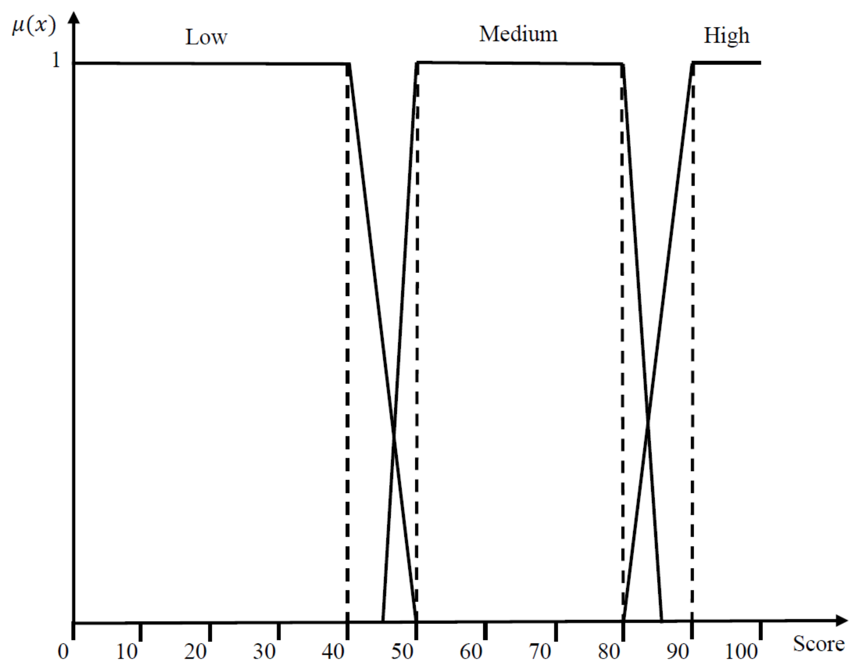

Figure 5.7 Trapezoidal Fuzzy Numbers for the Scores

To explain how the overall score is computed for each evaluation criterion and then translated to a linguistic rating, the following example is provided for the communications management criterion (C4), which includes five evaluation rules. If the consultant gets a "yes" in the first four rules and a "no" in the last rule for C4, the overall score of C4 will be 70 out of 100; that is because, according to the scores listed in Table 4.1 in the previous chapter, the last rule contributes to 30% of the overall score. This overall score corresponds to a medium performance rating. The rule concerning the use of BIM, or an equivalent digital system, was the rule in which the consultant received a "no." As a result, it is fair that the consultant gets a medium rating rather than a high one in C4 since BIM, which is one of the most powerful and effective ways of communication nowadays, is not used by the consultant. All the other evaluation criteria follow the same approach explained in the example.

In case the overall score S_{total} of a criterion lies in the overlapping area between the low and medium ratings (from 45 to 50), the following will take place:

- If S_{total} = 45, the rating will be low because the degree of membership in the medium rating is zero.
- If 45 < S_{total} < 47.5, the rating will be considered low because the degree of membership in the low rating is higher than that in the medium.
- If 47.5 < S_{total} < 50, the rating will be considered medium because the degree of membership in the medium rating is higher than that in the low.
- If S_{total} = 47.5, the rating will be considered medium because it will be mathematically approximated to the nearest whole number, which is 48.
- If S_{total} = 50, the rating will be medium because the degree of membership in the low rating is zero.

The same concept is applied in case the overall score of the criterion lies in the overlapping area between the medium and high ratings (from 80 to 85).

5.4.3 Utilization of the TOPSIS Component of the Fuzzy TOPSIS Technique

According to Ashrafzadeh et al. (2012), the TOPSIS method is based on the concept that the chosen alternative should have the shortest distance from the positive ideal solution, that is, the solution that maximizes the benefit criteria and minimizes the cost criteria, and that chosen alternative should have the longest distance from the negative ideal solution, which is the solution that maximizes the cost criteria and minimizes the benefit criteria. This implies that TOPSIS divides the criteria into two types: benefit criteria and cost criteria. Higher values are desired in the former, whereas the opposite is true in the latter. Since the QBS approach is adopted in this research, no cost criteria are included, and higher values are required for all evaluation criteria; thus, all criteria are benefit criteria. The output of TOPSIS is ranking of different alternatives, which in this study are consultants.

5.4.4 Steps of the Fuzzy TOPSIS Technique

The fuzzy TOPSIS approach entails a series of steps to obtain the ranking of different consultants, as shown in Figure 5.8.

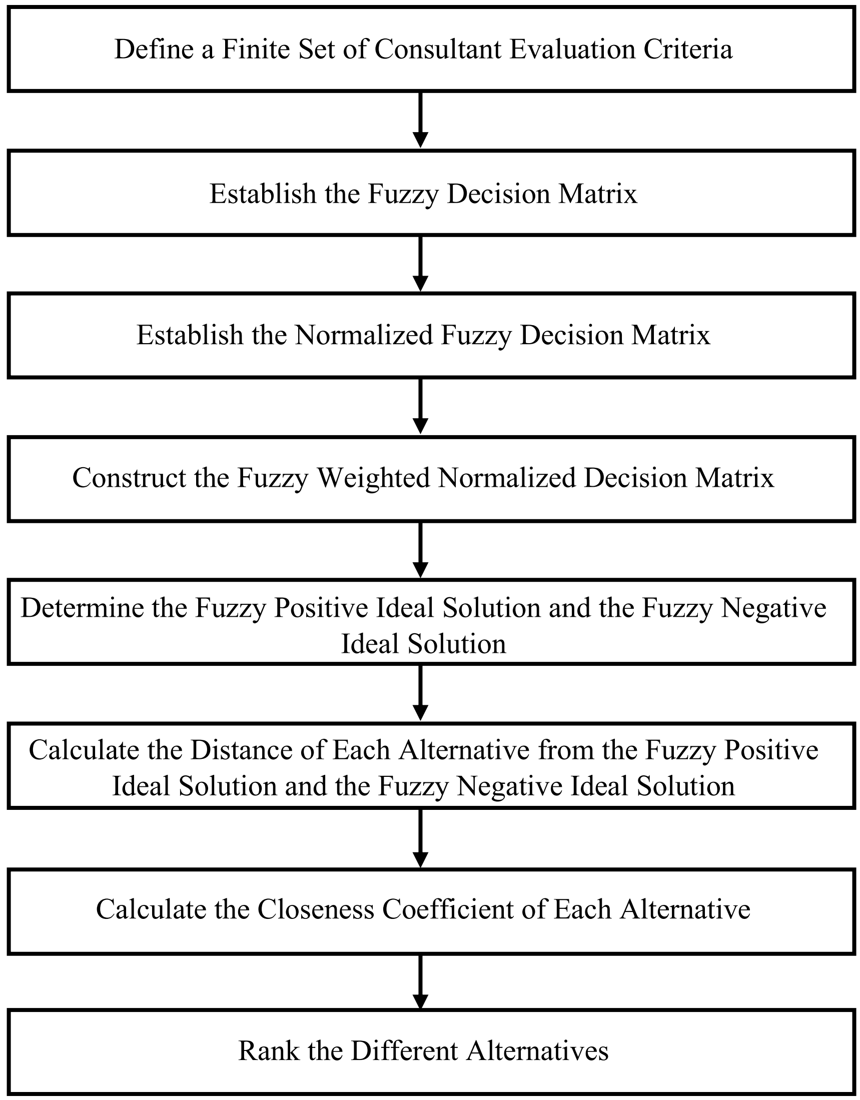

Figure 5.8 Steps of the Fuzzy TOPSIS Technique

5.4.4.1 Define a Finite Set of Consultant Evaluation Criteria

Defining a set of evaluation criteria is the first step in solving the consultant selection problem. The developed set of evaluation criteria was validated by industry experts, as discussed in detail in Chapter 3.

5.4.4.2 Establish the Fuzzy Decision Matrix

The general concept of constructing a decision matrix, as explained by Papathanasiou and Ploskas (2018), was applied in this research. The ratings represent the evaluation of the decision maker *k* for *m* alternatives, A_1, A_2, …, A_m. Each alternative (i.e., consultant) is evaluated separately with respect to each of the *n* criteria, C_1, C_2, …, C_n. The decision matrix $X = (x_{ij})_{m \times n}$ is formed by the decision maker's evaluations, and the vector of the criteria weights is represented as $W = (w_1, w_2, \ldots, w_n)$, where the total weight of the n criteria for each alternative is 1, as shown in Equation 5.2 (Papathanasiou & Ploskas, 2018).

$$\sum_{j=1}^{n} w_j = 1 \tag{5.2}$$

Since the evaluation rules measure the different evaluation criteria, to avoid making any subjective decisions, and the decision-maker is only required to check the fulfillment of the consultant to the requirements of each rule, only one decision-maker *k* is needed. Thus, the step of aggregating the opinions of different decision-makers is not performed in this study. The total score S_{total} of all rules forming each criterion *C* determines the linguistic rating (low, medium, high), where the maximum score S_{max} a consultant can get is 100 for each criterion *C*. After the model calculates the total scores of all criteria and converts them into linguistic ratings, these ratings are then represented by trapezoidal fuzzy numbers. Equations 5.3 and 5.4, provided by Papathanasiou and Ploskas (2018), represent the fuzzy decision matrix and the vector of criteria weights, respectively.

$$\widetilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \tag{5.3}$$

$$W = [w_1, w_2, \dots, w_n] \tag{5.4}$$

Where $\tilde{x}_{ij}$ is a linguistic variable representing the performance rating and w_j is a real number representing the weight of the criterion; $i = 1, 2, \dots, m$ and $j = 1, 2, \dots, n$. Since $\tilde{x}_{ij}$ is a linguistic variable, it can be represented by trapezoidal fuzzy numbers such that $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}, d_{ij})$.

5.4.4.3 Establish the Normalized Fuzzy Decision Matrix

Normalization takes place to have values that can be comparable by removing their units. Thus, values of the criteria weights are normalized, if needed, to have a sum of one. For the overall ranking, where all evaluation criteria are included, their sum is equal to one (100%.), and so normalization is not required. However, to obtain a separate ranking for the technical criteria category (47%) and another ranking for the managerial and organizational criteria category (53%), normalization is needed. That is because the sum of criteria weights in each category is not equal to 100%, and so the model automatically normalizes the criteria weights in these cases.

The trapezoidal fuzzy numbers, representing the scores, are normalized to have a range of zero to one rather than zero to 100, as indicated in Table 5.2.

Table 5.2 Linguistic Variables for the Ratings After Normalization

Linguistic Variable	**Trapezoidal Fuzzy Number**
Low	(0,0,0.40,0.50)
Medium	(0.45,0.50,0.80,0.85)
High	(0.80,0.90,1,1)

The normalized fuzzy decision matrix is represented by Equation 5.5 (Papathanasiou & Ploskas, 2018).

$$\tilde{R}= \left[\tilde{r}_{ij}\right]_{m\times n} \tag{5.5}$$

Since no cost criteria are involved, normalization is performed only for the benefit criteria B, using Equations 5.6 and 5.7 (Papathanasiou & Ploskas, 2018).

$$\tilde{r}_{ij}= \left(\frac{a_{ij}}{d_j^*}, \frac{b_{ij}}{d_j^*}, \frac{c_{ij}}{d_j^*}, \frac{d_{ij}}{d_j^*}\right), \quad j \in B, \quad i = 1, 2, \dots m \tag{5.6}$$

$$d_j^* = \max_i d_{ij}, \qquad \text{if } j \in B, \quad i = 1, 2, \dots m \tag{5.7}$$

5.4.4.4 Construct the Fuzzy Weighted Normalized Decision Matrix

The fuzzy weighted normalized decision matrix $\tilde{V}$ is created as described in Equations 5.8 and 5.9 (Papathanasiou & Ploskas, 2018).

$$\tilde{V}= \left[\tilde{v}_{ij}\right]_{m\times n}, \qquad i = 1, 2, \dots m, \quad j = 1, 2, \dots n \tag{5.8}$$

$$\tilde{v}_{ij} = \tilde{r}_{ij}(.)w_j, \quad i = 1, 2, \dots m, \quad j = 1, 2, \dots n \tag{5.9}$$

The criteria weights w_j are real numbers not linguistic variables.

5.4.4.5 Determine the Fuzzy Positive Ideal Solution and the Fuzzy Negative Ideal Solution

The fuzzy positive ideal solution (FPIS) and the fuzzy negative ideal solution (FNIS) are determined using Equations 5.10, 5.11, and 5.12 (Papathanasiou & Ploskas, 2018).

$$\text{FPIS} = A^+ = (\tilde{v}_1^+, \tilde{v}_2^+, \dots, \tilde{v}_n^+) \tag{5.10}$$

$$\text{FNIS} = A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-) \quad (5.11)$$

Since the normalized values of $\tilde{v}_{ij}$ range from zero to one, $\tilde{v}_j^+$ and $\tilde{v}_j^-$ are as follows:

$$\tilde{v}_j^+ = (1,1,1,1) \text{ and } \tilde{v}_j^- = (0,0,0,0), \qquad j = 1, 2, \dots n \quad (5.12)$$

5.4.4.6 Calculate the Distance of Each Alternative from the Fuzzy Positive Ideal Solution and the Fuzzy Negative Ideal Solution

Since the alternatives in this study are the consultants, the distance from the FPIS and the FNIS will be calculated for each consultant. The equation needed for measuring the distance between two fuzzy numbers differs according to the shape used for those fuzzy numbers (e.g., triangular, trapezoidal). Chen et al. (2006) used the vertex method to find the distance between two trapezoidal fuzzy numbers, as presented in Equation 5.13, such that $\tilde{m} = (m1, m2, m3, m4)$ and $\tilde{n} = (n1, n2, n3, n4)$ are two trapezoidal fuzzy numbers.

$$d(\tilde{m}, \tilde{n}) = \sqrt{\frac{1}{4}[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2 + (m_4 - n_4)^2]} \quad (5.13)$$

The distance of each alternative from the FPIS and the FNIS is determined using Equations 5.14 and 5.15 (Papathanasiou & Ploskas, 2018).

$$D_i^+ = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^+), \quad i = 1, 2, \dots m, \quad j = 1, 2, \dots n \quad (5.14)$$

$$D_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-), \quad i = 1, 2, \dots m, \quad j = 1, 2, \dots n \quad (5.15)$$

5.4.4.7 Calculate the Closeness Coefficient of Each Alternative

The closeness coefficient CC_i is required to obtain the ranking of different alternatives. The index CC_i reveals how near the alternative is to the FPIS (D_i^+) and how far it is from the FNIS (D_i^-) (Nofal & Hammad, 2020). The closeness coefficient of each alternative is calculated using Equation 5.16 (Papathanasiou & Ploskas, 2018).

$$CC_i = \frac{D_i^-}{D_i^+ + D_i^-}, \qquad i = 1, 2, \ldots m \tag{5.16}$$

5.4.4.8 Rank the Different Alternatives

Ranking alternatives is the final step in the implementation of the fuzzy TOPSIS technique. As explained by Papathanasiou and Ploskas (2018), the closer the closeness coefficient of the alternative is to one, the better it is. Thus, the value of the closeness coefficient determines the final ranking of the different alternatives (Papathanasiou & Ploskas, 2018).

5.5 Automation of the Consultant Evaluation and Ranking Process

5.5.1 Creation of Fuzzy TOPSIS Model Using Microsoft Excel

Microsoft Excel equations were initially used to build a fuzzy TOPSIS model template for the computerization of the consultant ranking process. The Excel template includes three sheets: one that calculates the overall ranking of consultants, another that calculates the consultants' ranking based only on technical criteria, and a third that only ranks consultants based on the managerial and organizational criteria. The steps of the fuzzy TOPSIS approach in the Excel template are similar to those explained earlier in this chapter. SUM, MAX, MIN, SQRT, and RANK are some of the Excel formulas utilized.

After the decision-maker checks the consultant's fulfillment of the evaluation rules' requirements, the trapezoidal fuzzy numbers representing the low, medium, and high ratings are fed into the

Excel template. The number of alternatives in the Excel template is assumed to be three; if this number changes, for example, if more alternatives are included, Excel formulas for the additional alternatives shall be copied. The output of the template is the: (1) overall ranking of consultants, (2) ranking of consultants for the technical criteria category, and (3) ranking of consultants for the managerial and organizational criteria category.

5.5.2 Creation of a Comprehensive Decision Support System Using Python

The three-step consultant evaluation and ranking process, summarized earlier in Figure 5.1, was coded in Python to automate the entire process. Four Python files were developed to conveniently analyze each of the three steps of the process: one file for each step and a file linking the results of the three other files together since the output of one file (i.e., one phase of the process) is the input to the other file. The combined file's final output is an overall ranking of different consultants, a ranking based on the technical criteria, and a ranking based on the managerial and organizational criteria.

The first file is responsible for coding the pre-evaluation phase of the process in which the user of the system (i.e., decision-maker) will be given a series of yes/no questions to do a quick screening and shortlisting operation before the detailed evaluation. In Python, the "if" statement was used to do this, as seen in Figure 5.9, which shows a portion of the developed code. These questions will be asked for each consultant.

```python
# Pre-evaluation yes/no questions for screening and shortlisting consultants
def eval_consultant(consultant):
    print("\n")
    print(style.UNDERLINE + style.BOLD + style.BLUE + "Pre-evaluation of {}".format(consultant))
    firm_capacity = input(style.RESET + "1. Does the Consultant have sufficient resources allocated for this project? ")
    if firm_capacity == "yes":
        firm_stability = input("2. Are the past, present, and future financial status of the Consultant stable? ")
        if firm_stability == "yes":
            relevant_experience = input("3. Does the Consultant have proven experience in similar nature, scope, "
                                        "and complexity projects? ")
            if relevant_experience == "yes":
                client_consultant_relationship = input("4. Is the Client-Consultant previous working relationship "
                                                       "satisfactory? ")
                if client_consultant_relationship == "yes":
                    referees = input("5. Would the two referees work with the Consultant again? ")
                    if referees == "yes":
```

Figure 5.9 A Portion of the Model for Screening and Shortlisting Consultants

For the second step of the process, a second Python file was created. This file includes all the evaluation criteria, evaluation rules, and the corresponding scores for those rules. Based on the decision-maker's answers to the evaluation rules (yes/no/not applicable), the total score for each criterion will be immediately calculated, which will then be automatically transformed to a low, medium, or high rating. The “if …elif …else” statement was used for this purpose, as shown in Figure 5.10. This step takes place for each consultant who has passed the screening phase.

```python
# Criterion 6
print(style.RESET + style.UNDERLINE + style.MAGENTA + "For Criterion #6 - Risk Management:")
list_c6 = []
criterion6_rule1 = input(style.RESET + "6.1 Retrospective risk identification: risks that have occurred in the "
                                       "past and for which knowledge in managing is available (e.g., the use of "
                                       "checklists, RIM, SWOT analysis, interview): ")
criterion6_rule2 = input("6.2 Prospective risk identification, which excludes past data (the use of creativity "
                         "tools (e.g., brainstorming, brainwriting, the Delphi technique, synectics): ")
criterion6_rule3 = input("6.3 Classification of risks (e.g., quality, safety, schedule, cost, etc.): ")
criterion6_rule4 = input("6.4 Demonstration of potential opportunities, not just threats: ")
criterion6_rule5 = input("6.5 Description of the risk analysis technique (e.g., quantitative) and assessment of "
                              "the likelihood and impact of each risk: ")
criterion6_rule6 = input("6.6 Proposed mitigation/response plan for each risk: ")

if criterion6_rule1 == "yes":
    c6_r1 = 1
elif criterion6_rule1 == "no":
    c6_r1 = 1
else:# for the "not applicable" answer
    c6_r1 = 0
list_c6.append(c6_r1)
```

Figure 5.10 A Portion of the Model for Obtaining Linguistic Ratings

As depicted in Figure 5.10, first, all the evaluation rules of the criterion are presented, and then the "if …elif …else" statement takes place for each rule; the "else" part of the statement in this figure denotes the situation in which the evaluation rule is not applicable, and the decision-maker is requested to enter "na" in this case. Following the elimination of all the non-applicable rules in each criterion, in case there are any, certain coded computations will be carried out to adjust the scores; a small portion of these calculations is presented in Figure 5.11. For example, if the non-applicable rules account for 30% of the total score of a criterion, which is originally 100%, the remaining 70% of the score will be the new 100%.

```python
for i in range(0, c6):
    scores_c6[i] = scores_c6[i] / sum_c6
    new_list_c6 = []

if criterion6_rule1 == "yes":
    criterion6_rule1 = scores_c6[0]
else:# for the "no" answer
    criterion6_rule1 = 0
new_list_c6.append(criterion6_rule1)
```

Figure 5.11 A Portion of the Model Computations After Eliminating the Non-Applicable Rules

The third step of the automated process involves the fuzzy TOPSIS method calculations. A small part of that code was obtained from Papathanasiou and Ploskas (2018); this part of the code includes converting the linguistic variables for the ratings into a fuzzy decision matrix and calculating the fuzzy weighted normalized decision matrix.

In step three of the process, the decision-maker is requested to specify the weight of each criterion, as shown in Figure 5.12. The recommended criteria weights are also provided by the system for the decision-maker, with a total of 47% for the technical criteria category and 53% for the managerial and organizational criteria category, as explained in Chapter 3.

```
print(style.BOLD + style.BLUE + "The recommended weights (%) for the Technical Criteria are: [C1=2, C2=4, C3=4, C4=3, "
                                "C5=2, C6=3, C7=3, C8=3, C9=3, C10=6, C11=2, C12=4, C13=4, C14=4]")

print(style.UNDERLINE + style.BOLD + style.MAGENTA + "NOTE: The total weight of the Technical Criteria should be 47%")
print(style.RESET + style.BOLD + style.RED + "Please enter the weights without the % sign")

criterion1_weight = float(input(style.RESET + "C1. Please enter the weight of the 'Proposal Quality' criterion: "))
c1_weight = criterion1_weight/100

criterion2_weight = float(input("C2. Please enter the weight of the 'Goals, Objectives and Tasks Comprehension' "
                               "criterion: "))
c2_weight = criterion2_weight/100

criterion3_weight = float(input("C3. Please enter the weight of the 'Detailed Specific Description of Project "
                               "Approach' criterion: "))
c3_weight = criterion3_weight/100
```

Figure 5.12 A Portion of the Model for Obtaining the Criteria Weights from the Decision-Maker

Figure 5.13 represents part of the calculations performed by the fuzzy TOPSIS model. A list of technical criteria is extracted from the original list containing all the criteria to obtain a ranking for the technical criteria separately; the same took place to get a ranking for the managerial and organizational criteria.

The decision-maker is allowed to enter the criteria weights because weights may differ from one project to another depending on the characteristics of the project. For example, in a project where high innovation is required, the decision-maker can increase the percentage of the innovation and value-added services criterion while maintaining a total of about 50% on the technical criteria category.

```
criteria_weights = [c1_weight, c2_weight, c3_weight, c4_weight, c5_weight, c6_weight, c7_weight, c8_weight, c9_weight,
                    c10_weight, c11_weight, c12_weight, c13_weight, c14_weight, c15_weight, c16_weight, c17a_weight,
                    c17b_weight, c17c_weight, c18_weight, c19_weight, c20_weight, c21_weight, c22_weight]

crw = norm_weight(criteria_weights)# normalize criteria weights

extracted_technical_list = criteria_weights[:14]# technical criteria are the first 14 criteria
norm_extracted_technical_list = norm_weight(extracted_technical_list)# normalize the weights of the extracted
                                                                      # technical criteria

extracted_managerial_list = criteria_weights[-10:]# managerial & organizational are the last 10 criteria
# total is 10 criteria not 8 since criterion C17 includes 3 separate project examples (c17a, c17b, and c17c)
norm_extracted_managerial_list = norm_weight(extracted_managerial_list)# normalize the weights of the extracted
                                                                        # managerial & organizational criteria

# "a" represents the range of scores for each linguistic rating
rating_ranges = [[0, 0, 40, 50],[45, 50, 80, 85],[80, 90, 100, 100]]# Low, Medium & High ranges of scores, respectively
max_value_range =(max(map(lambda x: x[-1],rating_ranges)))
a = {"Low": [rating_ranges[0][0]/max_value_range, rating_ranges[0][1]/max_value_range, rating_ranges[0][2]/
             max_value_range, rating_ranges[0][3]/max_value_range],
     "Medium": [rating_ranges[1][0]/max_value_range, rating_ranges[1][1]/max_value_range, rating_ranges[1][2]/
                max_value_range, rating_ranges[1][3]/max_value_range],
     "High": [rating_ranges[2][0]/max_value_range, rating_ranges[2][1]/max_value_range, rating_ranges[2][2]/
              max_value_range, rating_ranges[2][3]/max_value_range]}
```

Figure 5.13 A Portion of the Fuzzy TOPSIS Model Computations

The fourth file (combined file) reads from the three other files. To summarize how the decision support system works, when the combined file is run, the decision-maker will first be asked to enter some of the project characteristics and the weights of all the evaluation criteria, with recommended weights provided. After that, the total number and the names of the different consulting firms that will undergo the screening and shortlisting operation should be specified. Detailed evaluation will then take place for the eligible consultants using the evaluation rules, where the decision-maker is asked to provide yes/no/not applicable answers to these rules. The system will automatically calculate the low, medium, and high ratings, which will be utilized by the fuzzy TOPSIS model to reach the desired goal of ranking consultants.

To ensure that the Python code works properly in terms of the calculations performed by the fuzzy TOPSIS model, the Excel template described earlier in this chapter was used to validate the results. Both models, Python and Excel, gave the same closeness coefficient values with the same ranking of consultants.

5.6 Sensitivity Analysis

Saltelli et al. (2004) explained that sensitivity analysis was formerly thought of and described as a local measure of the effect of a given input on a particular output. It can also be defined as "The study of how the uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input" (Saltelli et al., 2004).

Sensitivity analysis was performed by running the developed model through many different scenarios to ensure that the model is sensitive to changes in its input and to make sure that its output makes sense. For example, the number of consultants to be screened prior to the evaluation was changed, and the yes/no answers to the pre-evaluation inquiries were also changed. For the evaluation rules, the yes/no/not applicable answers were randomly changed several times to ensure that the final score for each criterion is properly calculated and gives the correct conversion to low, medium, and high ratings. The model output, which is the ranking of consultants, was different each time in a way that makes sense in terms of the produced values. These checks took place for both the Python and Excel models.

5.7 Experts Validation of the Developed Decision Support System

5.7.1 Experts Feedback and Comments on the Developed Decision Support System

During the meeting that was held with experts from the industry to validate the evaluation rules used for measuring different criteria, experts were also asked to validate the entire decision support system. Initially, the whole model presented to the experts included yes/no answers to the evaluation rules without the not applicable option as an answer for the rule. The experts mentioned that the evaluation rules used for the large industrial type of projects might not be needed in many cases where small projects take place. They also pointed out that the model should be adaptable and flexible in terms of adjusting some parameters if needed since project characteristics differ from one project to another.

For the evaluation rules, the experts suggested checking the vendor performance management (VPM) evaluation form for consultants (post-performance evaluation), used by Alberta Infrastructure (n.d.), which may contain some essential points that can be considered for evaluation at an early stage (bidding stage) as well.

The experts highlighted the need to keep the 47%-53% kind of split between the (1) technical criteria category and (2) managerial and organizational criteria category, respectively, which is about 50% for each category. They stated that this idea works for all projects, and that is why it is good to keep this division between them. As explained in Chapter 3, this division was obtained from the analysis of 85 documents used by industry clients (public organizations in Alberta) for evaluating and selecting consultants.

Furthermore, the experts mentioned the usefulness of being able to reuse some of the information they provided for a specific project with specific characteristics and criteria weights in other projects with similar features so that the decision-maker does not have to re-enter the same data for those projects.

5.7.2 Modifications Performed to Incorporate the Experts Comments

Some changes were made in response to the experts' comments. These comments are incorporated in Chapters 4 and 5. The not applicable option for the rule was introduced to the decision support system in case the rule is not needed for that specific project. Accordingly, the Python model was adjusted in such a manner that, if any non-applicable rules are found, they are excluded from the evaluation process by making certain modifications to the computations without affecting the calculations of the other rules' scores. For example, if one or more rules are not relevant for a certain criterion in a project, the system will automatically remove them when the user answers "no." The remaining relevant criteria will then be given adjusted scores, resulting in a total of 100% on the applicable rules' scores for each criterion

Because various project needs vary, criteria weights were modified from being pre-defined by the system to being input by the user to make the system more flexible. If a criterion is not necessary for a project, for example, it might be given a zero weight. The user can alternatively utilize the system's recommended weights, which will be shown for the user to review before entering any weights.

As suggested by the experts, consultant post-performance evaluation forms, which are part of the Alberta's VPM program for infrastructure projects (Alberta Infrastructure, n.d.), were checked to analyze the KPIs used. Accordingly, some points were obtained from the aspects explained in these forms and were included as evaluation rules for measuring the criteria. These points were added to the rules in Table 4.1 and Table 4.2 in Chapter 4, and each one is explained as follows:

- For the quality of design/safety aspect in the form, it included having the design at each stage fulfilling basic legislative requirements, codes, and standards related to safety, accessibility, and community needs. Hence, this was added as the eighth rule for measuring the "Detailed Specific Description of the Project Approach (Work Plan)" criterion (additional rule 3.8). Furthermore, under the same aspect of quality of design/safety aspect, a plan for providing a final product that functions (an effective, efficient, convenient, safe product that is easy to operate and maintain) was another rule considered the same criterion (additional rule 3.9). Because the form is concerned with post-evaluation rather than pre-evaluation, the word "plan" was added to suit the bidding evaluation stage.
- Regarding the quality control and inspection process, the post-performance evaluation form included site monitoring/reviews and reporting; this part was added to the "Quality Assurance and Quality Control" criterion as part of an existing rule (rule 10.6).
- Under the "Project Organizational Chart and Description of Team Members" criterion, a rule related to providing proficient contract administration, which is accurate, effective, and organized, was added; for this rule, the consultant is required to provide a description of the contract administrator who will be assigned to that specific project (additional rule 20.6).

Some other KPIs mentioned in the same post-performance evaluation forms were identified from the analyzed RFPs and so were not repeated.

To keep the 47% and 53% division between the technical criteria category and the managerial and organizational criteria category, respectively, the user of the decision support system will be alerted, via a printed message, to consider these percentages while entering the criteria weights so that they can maintain about 50% for each category.

Regarding the experts' opinion of having the option to use the same information they entered for a project in other projects that have common characteristics, questions related to some project characteristics will be asked to the user of the system at the beginning of the evaluation process, and then the user will be asked to enter the criteria weights for that project. Hence, some project characteristics, identified from the literature, include project complexity, project type, and project size, which were mentioned by Chan et al. (2004) as project-related factors that impact the success of a project, and were also mentioned by Ng and Skitmore (1999) as contractor prequalification criteria. According to ACEC-BC (2016), projects which can be classified as small are the ones with fees less than $75,000, projects with fees from $75,000 to $200,000 can be classified as medium projects, and large projects are those with fees greater than $200,000.

In addition to the project characteristics outlined in the previous paragraph, environmental considerations, sustainability, and green design, as well as innovation, are key elements that have recently gained attention. For sustainability, it was mentioned by Chinowsky and Kingsley (2009) as a social-related aspect. Also, since projects can be driven by schedule, resources, etc., the main project driver was added as one of the considered project categorization factors.

The system's flexibility and adaptability were improved as a result of the changes made. It is critical to set a limit on the system's flexibility to preserve the system's objectivity. That is because too much flexibility (e.g., enabling the user to input whatever they desire) increases subjectivity in the consultant evaluation and selection process, which is in direct opposition to the fundamental aim of minimizing subjectivity and bias in the decision-making process.

Chapter 6: Application of the Developed Decision Support System

6.1 Introduction

This chapter represents the implementation of the developed methodology for objective selection of engineering consultants and application of the constructed decision support system. The presented numerical example is comprehensive and will be explained in detail from the start (the user input) to the end (the analytical model output, which is the ranking of consultants).

6.2 The User Input to the System

The first step in employing the developed decision support system is the need for the technical criteria weights as well as the managerial and organizational criteria weights to be entered by the user, according to the project characteristics inserted by the user, as shown in Figure 6.1.

```
Project Characteristics:
Q1. What is the type of the project? infrastructure
Q2. What is the size of the project? (the following are recommended: Small Projects < $75k, $75k <= Medium Projects <= $200k, Large Projects > $200k) medium
Q3. What is the level of complexity of the project? medium
Q4. What is the expected level of environmental, sustainability and green design considerations in the project? low
Q5. What is the expected level of innovation in the project? low
Q6. What is the main project driver? (e.g., schedule, resources) resources


The recommended weights (%) for the Technical Criteria are: [C1=2, C2=4, C3=4, C4=3, C5=2, C6=3, C7=3, C8=3, C9=3, C10=6, C11=2, C12=4, C13=4, C14=4]
NOTE: The total weight of the Technical Criteria should be 47%
Please enter the weights without the % sign
C1. Please enter the weight of the 'Proposal Quality' criterion: 2
C2. Please enter the weight of the 'Goals, Objectives and Tasks Comprehension' criterion: 4
C3. Please enter the weight of the 'Detailed Specific Description of Project Approach' criterion: 4
C4. Please enter the weight of the 'Communication Management (Project Communication Plan)' criterion: 3
C5. Please enter the weight of the 'Stakeholder Management' criterion: 2
C6. Please enter the weight of the 'Risk Management' criterion: 3
C7. Please enter the weight of the 'Safety Management' criterion: 3
C8. Please enter the weight of the 'Environmental Management' criterion: 3
C9. Please enter the weight of the 'Innovation and Value-added Services' criterion: 3
C10. Please enter the weight of the 'Quality Assurance and Quality Control' criterion: 6
C11. Please enter the weight of the 'Dispute/Conflict Management and Resolution Approach' criterion: 2
C12. Please enter the weight of the 'Tasked-based Schedule' criterion: 4
C13. Please enter the weight of the 'Schedule Control Approach' criterion: 4
C14. Please enter the weight of the 'Cost Control Approach' criterion: 4
Note that the total weight entered by the user for the Technical Criteria is: 47.0%


The recommended weights (%) for the Managerial and Organizational Criteria are: [C15=4, C16=4, C17a=5, C17b=5, C17c=5, C18=2, C19=10, C20=5, C21=7, C22=6]
NOTE: The total weight of the Managerial and Organizational Criteria should be 53%
Please enter the weights without the % sign
C15. Please enter the weight of the 'Overview of the Organization' criterion: 4
```

Figure 6.1 User Input to the Decision Support System

For instance, if the decision-maker enters “high” for the level of innovation in that project, the weight of the innovation and value-added services criterion should increase in this case. The same concept can be applied to all other evaluation criteria according to the characteristics of the project. The recommended weights, shown in Figure 6.1, are advised for standard projects that have no special requirements. In the example presented in this chapter, weights were kept as recommended; for example, “low” was assumed to be the expected level of innovation, and so the weight of the innovation and value-added services criterion was kept as recommended (3%). However, the decision-maker should maintain a total weight of 100% on all the criteria: around 50% on the technical criteria and the same for the managerial and organizational criteria for all projects, as advised by the industry experts.

6.3 The Pre-evaluation Stage of the Process

Following the user input stage, the decision-maker will be asked to specify the total number of consultants that will be screened to check the eligibility of each consultant for the detailed evaluation stage, as well as the names of the consultancy firms. After that, the pre-evaluation inquiries will be asked to the decision-maker for each consultancy firm name entered, as presented in Figure 6.2. A yes/no answer is required to determine the eligibility. In the presented example, it is assumed Companies BB, DD, and EE are the ones eligible for the detailed evaluation stage.

```
Please enter the total number of Consultants to be screened prior to evaluation: 5


Please enter the name of each Consultant:
Company AA
Company BB
Company CC
Company DD
Company EE
['Company AA', 'Company BB', 'Company CC', 'Company DD', 'Company EE']


Pre-evaluation of Company AA
1. Does the Consultant have sufficient resources allocated for this project? yes
2. Are the past, present, and future financial status of the Consultant stable? no
FAILED! The Consultant is not eligible for the next evaluation stage



Pre-evaluation of Company BB
1. Does the Consultant have sufficient resources allocated for this project? yes
2. Are the past, present, and future financial status of the Consultant stable? yes
3. Does the Consultant have proven experience in similar nature, scope, and complexity projects? yes
4. Is the Client-Consultant previous working relationship satisfactory? yes
5. Would the two referees work with the Consultant again? yes
6. Is the health and safety record of the Consultant on previous projects acceptable? yes
7. Does the Consultant have a record of unjustified claims in past projects? no
8. Has the Consultant failed to complete a contract, had a recent termination of a contract by the Client, or had withdrawn from a contract prematurely? no
PASSED! The Consultant is eligible for the next evaluation stage
```

Figure 6.2 Pre-evaluation Stage

6.4 The Detailed Evaluation Stage of the Process

After the pre-evaluation stage is completed for all consultants, yes/no/not applicable questions will be asked to the decision-maker regarding the evaluation rules used for measuring the criteria, as shown in Figure 6.3, to determine the linguistic ratings (low, medium, and high) objectively. Detailed evaluation for the eligible consultants will commence in order, from the first company that has passed the pre-evaluation stage until the last eligible one. In the presented example, all the evaluation rules for all the criteria are assumed to be applicable; hence, yes/no answers to the rules are required.

If an entire criterion is not applicable, all its evaluation rules must be answered with not applicable (na). The user should also enter zero for this criterion's weight from the start; therefore, a message from the system will be printed for the user to alert them about this matter if they enter "na" for all the evaluation rules of a single criterion.

```
Evaluation of Company BB

(1) Evaluation of Technical Criteria - Project Comprehension and Methodology Criteria:

For Criterion #1 - Proposal Quality:
1.1 Complete proposal: yes
1.2 Detailed proposal with all the relevant information: yes
1.3 Clear proposal in terms of work description: yes
1.4 Well-presented proposal: no
The total score for the 'Proposal Quality' criterion is Medium


For Criterion #2 - Goals, Objectives, and Tasks Comprehension:
2.1 Scope of work comprehension: yes
2.2 Detailed goals, objectives, and deliverables: yes
2.3 Roles and responsibilities comprehension: yes
2.4 Inclusion of the consultant's role in construction (e.g., shop drawing review and approval, final walkthroughs, construction inspections): no
2.5 Deep understanding of construction QA/QC: yes
2.6 Design vision - Illustrative project comprehension (e.g., plans, sketches): no
The total score for the 'Goals, Objectives, and Tasks Comprehension' criterion is Medium


For Criterion #3 - Detailed Specific Description of Project Approach (Work Plan):
3.1 Work Plan matches the RFP requirements: yes
3.2 Methodology rationale and constructability of design: yes
3.3 Inclusion of project specific required approaches: yes
3.4 Description of included, excluded and optional services, and those provided by others: yes
3.5 Integration of cross-disciplinary perspectives: yes
3.6 Integration of sub-consultants and/or specialists' services: yes
3.7 Implementation of lean principles (e.g., identify and map value stream, create flow via waste removal, respond to customer pull, and strive for perfection): yes
3.8 Design at each stage fulfills basic legislative requirements, codes, and standards related to safety, accessibility, and community needs: yes
3.9 Clear plan for providing a final product that functions; a product that is effective, efficient, convenient, safe, and easy to operate and maintain: yes
The total score for the 'Detailed Specific Description of Project Approach (Work Plan)' criterion is High
```

Figure 6.3 Detailed Evaluation Stage

6.5 The Fuzzy TOPSIS Stage

The Fuzzy TOPSIS part of the analytical model collects all the low, medium, and high ratings for all the eligible consultants to perform all the required computations to obtain the ranking of consultants.

6.5.1 The Fuzzy TOPSIS Computations

The scientific calculations performed by the developed Python model are not seen by the user; the user only sees the ranking of different consultants in a fraction of a second. Table 6.1 lists the criteria weights entered by the user, and Table 6.2 shows all the low, medium, and high ratings generated by the model based on the answers to the evaluation rules. Criteria weights are similar for all consultants, whereas the linguistic performance ratings differ from one consultant to the other.

Table 6.1 Criteria Weights

S.N.	Criterion	Criterion Weight %
C1	Proposal Quality	2
C2	Goals, Objectives, and Tasks Comprehension	4
C3	Detailed Specific Description of Project Approach (Work Plan)	4
C4	Communications Management	3
C5	Stakeholder Management	2
C6	Risk Management	3
C7	Safety Management	3
C8	Environmental Management	3
C9	Innovation and Value-Added Services	3
C10	Quality Assurance and Quality Control	6
C11	Dispute/ Conflict Management and Resolution Approach	2
C12	Tasked-Based Schedule	4

S.N.	Criterion	Criterion Weight %
C13	Schedule Control Approach	4
C14	Cost Control Approach	4
C15	Overview of the Organization	4
C16	Approaches to Lessons Learned and Knowledge Sharing inside the Firm	4
C17a	Relevant Project A Completed by the Firm in the Past 5 Years	5
C17b	Relevant Project B Completed by the Firm in the Past 5 Years	5
C17c	Relevant Project C Completed by the Firm in the Past 5 Years	5
C18	Ability to Create Long-Term Relationships with Clients	2
C19	Project Leader Credentials	10
C20	Project Organizational Chart and Description of Team Members	5
C21	Project Team Qualifications and Experience	7
C22	Project Team Collaborative Projects	6

Table 6.2 Linguistic Ratings of the Companies Under the Criteria

S.N.	Company BB	Company DD	Company EE
C1	Medium	Low	High
C2	Medium	Low	Low
C3	High	Medium	Low
C4	Low	Medium	High
C5	Low	Medium	Medium
C6	Low	Low	High
C7	Medium	Low	Low
C8	Medium	High	Low
C9	Low	Medium	Low
C10	High	Medium	Medium
C11	Medium	Low	Medium
C12	Medium	High	Medium
C13	Medium	Medium	Low

S.N.	Company BB	Company DD	Company EE
C14	Low	Low	Low
C15	Medium	Low	Medium
C16	High	Low	High
C17a	Medium	Low	Medium
C17b	Medium	High	Medium
C17c	Low	Medium	Medium
C18	High	Medium	Low
C19	Medium	Low	Low
C20	Medium	Medium	High
C21	High	Low	Medium
C22	Medium	Low	Medium

To recall from Chapter 5, the trapezoidal numbers representing the low rating are (0,0,40,50), medium rating is translated to (45,50,80,85), and it is (80,90,100,100) for the high rating. Accordingly, the low, medium, and high ratings in Table 6.2 will be converted into these trapezoidal numbers. Normalization will then take place to have a maximum value of one for the scores instead of 100. For the criteria weights, their total is 100%, and so for the overall ranking, normalization is not required; however, normalization will occur in case of the separate ranking required for the technical criteria category and another ranking for the managerial and organizational criteria category, since the total weight of the criteria in each category separately is not equal to 100%.

The fuzzy weighted normalized decision matrix, presented in Table 6.3, is then constructed by multiplying the weight of each criterion to each of the four normalized fuzzy numbers (forming the trapezoidal shape); this takes place for every linguistic rating. For the matrix shown in Table 6.3, the criteria are represented horizontally, and the alternatives (consultants) are shown vertically because the number of criteria is too big to be displayed in another way. Also, the numbers in the same table are approximated to the nearest two decimal places instead of three to fit all the numbers in one table.

Table 6.3 The Fuzzy Weighted Normalized Decision Matrix

S.N.	Company BB	Company DD	Company EE
C1	(0.01, 0.01, 0.02, 0.02)	(0.00, 0.00, 0.01, 0.01)	(0.02, 0.02, 0.02, 0.02)
C2	(0.02, 0.02, 0.03, 0.03)	(0.00, 0.00, 0.02, 0.02)	(0.00, 0.00, 0.02, 0.02)
C3	(0.03, 0.04, 0.04, 0.04)	(0.02, 0.02, 0.03, 0.03)	(0.00, 0.00, 0.02, 0.02)
C4	(0.00, 0.00, 0.01, 0.02)	(0.00, 0.02, 0.02, 0.03)	(0.02, 0.03, 0.03, 0.03)
C5	(0.00, 0.00, 0.01, 0.01)	(0.01, 0.01, 0.02, 0.02)	(0.01, 0.01, 0.02, 0.02)
C6	(0.00, 0.00, 0.01, 0.02)	(0.00, 0.00, 0.01, 0.02)	(0.02, 0.03, 0.03, 0.03)
C7	(0.01, 0.02, 0.02, 0.03)	(0.00, 0.00, 0.01, 0.02)	(0.00, 0.00, 0.01, 0.02)
C8	(0.01, 0.02, 0.02, 0.03)	(0.02, 0.03, 0.03, 0.03)	(0.00, 0.00, 0.01, 0.02)
C9	(0.00, 0.00, 0.01, 0.02)	(0.01, 0.02, 0.02, 0.03)	(0.00, 0.00, 0.01, 0.02)
C10	(0.05, 0.05, 0.06, 0.06)	(0.03, 0.03, 0.05, 0.05)	(0.03, 0.03, 0.05, 0.05)
C11	(0.01, 0.01, 0.02, 0.02)	(0.00, 0.00, 0.01, 0.01)	(0.01, 0.01, 0.02, 0.02)
C12	(0.02, 0.02, 0.03, 0.03)	(0.03, 0.04, 0.04, 0.04)	(0.02, 0.02, 0.03, 0.03)
C13	(0.02, 0.02, 0.03, 0.03)	(0.02, 0.02, 0.03, 0.03)	(0.00, 0.00, 0.02, 0.02)

S.N.	Company BB	Company DD	Company EE
C14	(0.00, 0.00, 0.02, 0.02)	(0.00, 0.00, 0.02, 0.02)	(0.00, 0.00, 0.02, 0.02)
C15	(0.02, 0.02, 0.03, 0.03)	(0.00, 0.00, 0.02, 0.02)	(0.02, 0.02, 0.03, 0.03)
C16	(0.03, 0.04, 0.04, 0.04)	(0.00, 0.00, 0.02, 0.02)	(0.03, 0.04, 0.04, 0.04)
C17a	(0.02, 0.03, 0.04, 0.04)	(0.00, 0.00, 0.02, 0.03)	(0.02, 0.03, 0.04, 0.04)
C17b	(0.02, 0.03, 0.04, 0.04)	(0.04, 0.05, 0.05, 0.05)	(0.02, 0.03, 0.04, 0.04)
C17c	(0.00, 0.00, 0.02, 0.03)	(0.02, 0.03, 0.04, 0.04)	(0.02, 0.03, 0.04, 0.04)
C18	(0.02, 0.02, 0.02, 0.02)	(0.01, 0.01, 0.02, 0.02)	(0.00, 0.00, 0.01, 0.01)
C19	(0.05, 0.05, 0.08, 0.09)	(0.00, 0.00, 0.04, 0.05)	(0.00, 0.00, 0.04, 0.05)
C20	(0.02, 0.03, 0.04, 0.04)	(0.02, 0.03, 0.04, 0.04)	(0.04, 0.05, 0.05, 0.05)
C21	(0.06, 0.06, 0.07, 0.07)	(0.00, 0.00, 0.03, 0.04)	(0.03, 0.04, 0.06, 0.06)
C22	(0.03, 0.03, 0.05, 0.05)	(0.00, 0.00, 0.02, 0.03)	(0.03, 0.03, 0.05, 0.05)

In the next step, the fuzzy positive ideal solution and the fuzzy negative ideal solution are determined, as explained in detail in Chapter 5. The defuzzification process takes place by converting the fuzzy values into crisp values. The results are summarized in Table 6.4; this table includes the distance of each alternative from the positive ideal solution D_i^+, the distance of each alternative from the negative ideal solution D_i^-, the closeness coefficient CC_i, and the overall ranking of each consultant.

Table 6.4 Overall Ranking Results

Alternative	$\boldsymbol{D_i^+}$	$\boldsymbol{D_i^-}$	$\boldsymbol{CC_i}$	**Overall Ranking**
Company BB	0.142	0.324	0.696	1
Company DD	0.319	0.147	0.315	3
Company EE	0.232	0.234	0.502	2

Figure 6.4 illustrates a comparison between the results of the overall ranking, where the distance of each company from the positive ideal solution, the distance of each company from the negative ideal solution, and the closeness coefficients are presented.

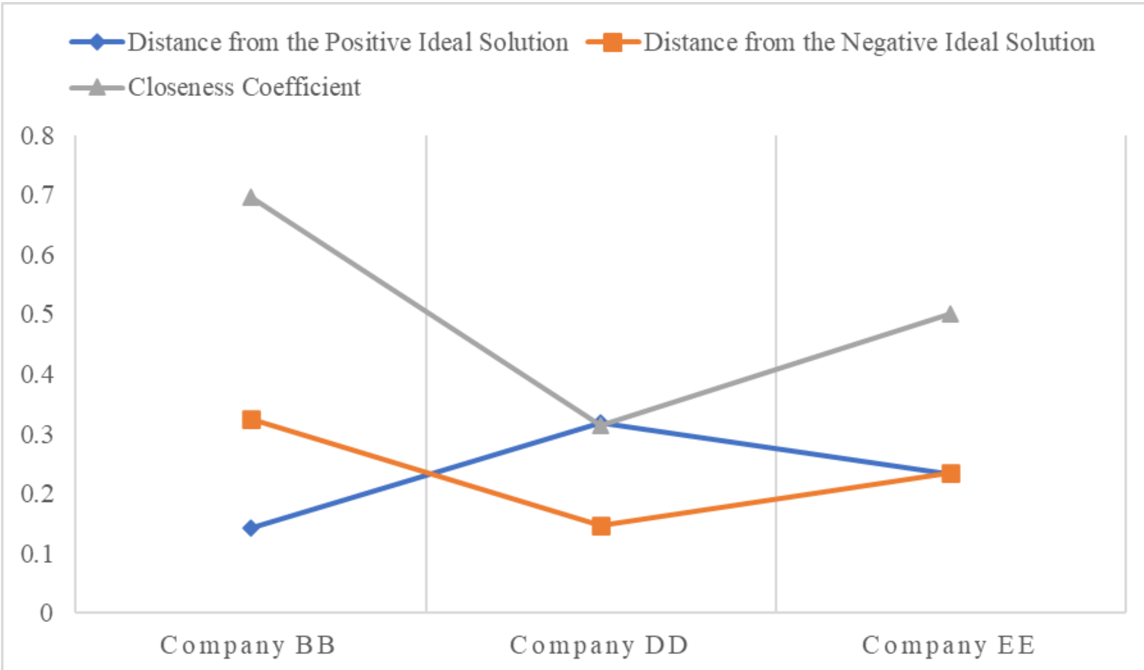

Figure 6.4 Comparison between the Overall Ranking Results

Since the model provides a ranking for the technical criteria category as well as the managerial and organizational criteria category, Table 6.5 and Table 6.6 summarize the results for each category, respectively.

Table 6.5 Technical Criteria Ranking Results

Alternative	D_i^+	D_i^-	CC_i	**Technical Criteria Ranking**
Company BB	0.193	0.263	0.576	1
Company DD	0.240	0.217	0.475	2
Company EE	0.297	0.159	0.348	3

Table 6.6 Managerial and Organizational Criteria Ranking Results

Alternative	D_i^+	D_i^-	CC_i	Managerial and Organizational Criteria Ranking
Company BB	0.096	0.378	0.798	1
Company DD	0.390	0.084	0.177	3
Company EE	0.174	0.300	0.631	2

Figure 6.5 depicts how the Python model shows the ranking. The Python model outputs were compared to the results from the Microsoft Excel template, and both yielded the same results. The Python model results are sorted from the highest to the lowest-ranked consultant.

```
OVERALL ranking of Consultants from the highest to the lowest is: 
Company BB    0.696
Company EE    0.502
Company DD    0.315

Ranking of Consultants from the highest to the lowest for the Technical Criteria only is: 
Company BB    0.576
Company DD    0.475
Company EE    0.348

Ranking of Consultants from the highest to the lowest for the Managerial and Organizational Criteria only is: 
Company BB    0.798
Company EE    0.631
Company DD    0.177
```

Figure 6.5 The Final Output of the Analytical Python Model

The results indicate that Company BB is the most qualified in every category: overall, technical, and managerial and organizational.

One of the major advantages of obtaining a breakdown for the overall ranking is that if two companies, for example, have a nearly identical ranking, the ranking in terms of the technical criteria category, as well as the managerial and organizational criteria category, can be analyzed separately to check whether the overall ranking of these companies is nearly similar because of the former category or the latter category, or both.

Chapter 7: Conclusion

7.1 Summary

Different procurement methods exist for evaluating and selecting engineering consultants. Clients, especially from the public sector, prefer priced based selection, although it has many shortcomings. On the other hand, the QBS procurement method, which excludes price criteria, considers essential skills and capabilities that the consultant evaluation and selection process relies on to decide upon the most competent consultant for a particular project. Hence, there was a need for determining all the necessary criteria which are vital for proper and comprehensive evaluation of consultants. For example, the future of construction is moving towards being sustainable and smart (i.e., innovative), and thus both aspects were covered.

A theoretical consultant evaluation and selection model was developed. This model comprises a standard set of evaluation criteria and sub-criteria, which were identified from the analyzed RFP documents and literature, with their weights. Because those criteria are qualitative, scientific research was conducted to find an objective solution to measure them. Decision-making rules were found to be the most suitable approach. Accordingly, evaluation rules were determined from the literature, as well as the descriptions of the criteria, sub-criteria, and proposal requirements in the analyzed dataset. Consultant post-performance evaluation forms, used by Alberta Infrastructure, were also checked to look for any additional evaluation rules which may be necessary.

For the analytical model development, fuzzy TOPSIS was found to be the suitable approach for dealing with the consultant evaluation and ranking problem after a review of the literature to understand how different MCDM techniques work. Everything in fuzzy logic is a matter of degree, and it does not deal with crisp values, whereas TOPSIS works with exact values and performs mathematical computations to provide the ranking of consultants. Scores were assigned to the developed evaluation rules to measure the low, medium, and high ratings for the criteria. These ratings were then translated by the fuzzy logic technique into a range of fuzzy numbers, which were dealt with by the fuzzy TOPSIS model. The entire process was coded in Python to automate it. As a result, the primary goal of this research was achieved, which is the development of an automated decision support system to aid in evaluating and selecting competent consultants with minimal subjectivity.

7.2 Conclusion

It can be concluded from this research that QBS is the proper procurement method for determining competent consultants since the inclusion of price usually impacts the analysis of the consultant qualifications. A complete set of consultant evaluation criteria was identified, and the statistical analysis of 85 RFP documents resulted in the determination of the weights for the main criteria categories. In addition, the problem of subjective decisions was addressed through the establishment of evaluation rules for measuring criteria. Fuzzy TOPSIS, for multi-criteria decision-making, was utilized to deal with a significant real-life problem, where trapezoidal fuzzy numbers were used instead of triangular ones because the trapezoid shape is more suitable for dealing with the consultant selection problem. Finally, the decision support system was validated by industry experts, including validation of the evaluation criteria, evaluation rules, and the system as a whole, and the constructed analytical model can be used as a tool to objectively assist owners in selecting qualified consultants.

For the advantages of the developed decision support system, it (1) increases objectivity and improves transparency, fairness, and consistency in the consultant evaluation process, as well as systemizes it, (2) screens and shortlists consultants for a quick review of some essential aspects before the detailed evaluation, (3) performs a detailed evaluation of eligible consultants using the identified set of criteria, (4) minimizes the need for group decision-making through the employment of the evaluation rules, (5) enhances the level of innovation and sustainability considerations in construction projects because consultants are not under the usual financial pressure that generally affects the quality of the product, (6) provides a reliable system that is easy to understand and use by decision-makers, (7) establishes an adaptable and flexible system that can be utilized for different projects by eliminating any non-applicable criteria and evaluation rules as well as changing the criteria weights based on the project characteristics, and (8) provides a breakdown for the ranking of consultants.

7.3 Limitations

The analyzed documents are RFPs used by public owners in Alberta to evaluate and select consultants. Therefore, limitations of the model arise from the need to integrate client documents from outside Alberta to study the different evaluation criteria and criteria weights used in those documents. In addition, three experts from the industry were involved in the model validation process. This may be viewed as a limitation, as more experts from different companies were needed to form a larger panel of experts.

7.4 Recommendations for Future Work

Since the analyzed RFP documents are used by public owners in Alberta only, the dataset can be extended by including RFPs from other provinces in Canada. In addition, the developed set of evaluation criteria and sub-criteria can be updated from time to time based on the market changes. For example, analyzing crisis management and adding it as an evaluation criterion, where the consultant shall be asked to provide a plan for managing a crisis if it occurred.

The developed computerized model can be enriched to include the ability to save templates for various project categories, allowing decision-makers to save their inputs (project characteristics, criteria weights, and any non-applicable evaluation rules) for a certain project and reuse them in other projects that have similar characteristics and requirements. The management staff of the organization can hold a meeting just to agree on the criteria weights to be used for each project template.

Furthermore, the developed decision support system can be added online and made accessible for owners to assist them in evaluating and selecting consultants. It can also be utilized to assist in the selection of competent contractors, which can take place after a thorough analysis of all the evaluation criteria and evaluation rules needed for assessing contractors.

References

Abdelrahman, M., Zayed, T., & Elyamany, A. (2008). Best-Value Model Based on Project Specific Characteristics. *Journal of Construction Engineering and Management*, *134*(3), 179–188. https://doi.org/10.1061/(asce)0733-9364(2008)134:3(179)

Agarwal, P., Sahai, M., Mishra, V., Bag, M., & Singh, V. (2011). A review of multi-criteria decision making techniques for supplier evaluation and selection. *International Journal of Industrial Engineering Computations*, *2*(4), 801–810. https://doi.org/10.5267/j.ijiec.2011.06.004

AIA (American Institute of Architects). (2015). QBS manual, qualifications-based selection: When quality and value matter, 28. Madison, WI: ACEC Wisconsin & AIA Wisconsin.

Alberta Infrastructure. (n.d.). *Consultant Performance Evaluation*. https://www.alberta.ca/assets/documents/infra-vpm-consultant-performance-evaluation.pdf

APWA (American Public Works Association). (n.d.). *Qualifications Based Selection of Professional Services Consultants*. http://www2.apwa.net/Documents/Qualifications_Based_Selec_Prof_Svs_Consult%281%29.pdf

Arditi, D., & Gunaydin, H. M. (1997). Total quality management in the construction process. *International Journal of Project Management*, *15*(4), 235–243. https://doi.org/10.1016/S0263-7863(96)00076-2

Arroyo, P. (2014). *Exploring decision-making methods for sustainable design in commercial buildings*. Ph.D. Thesis, University of California, Berkeley.

Arroyo, P., Tommelein, I., & Ballard, G. (2012). Deciding a sustainable alternative by 'choosing by advantages' in the AEC industry. In *Proc. 20th Conf. of the International Group for Lean Construction (IGLC), San Diego, CA* (pp. 41-50).

Ashrafzadeh, M., Rafiei, F., Isfahani, N., & Zare, Z. (2012). Application of fuzzy TOPSIS method for the selection of Warehouse Location: A Case Study. *Interdisciplinary Journal of Contemporary Research in Business*, *3*(9), 655–671.

Association of Consulting Engineering Companies-British Columbia (ACEC-BC). (2016). User guide to implementing qualifications-based selection: best practices for selecting your design professional. https://www.acec-bc.ca/media/43176/acec-bc-user-guide-to-implementing-qbs.pdf

Atkinson, R. (1999). Project management: Cost, time and quality, two best guesses and a phenomenon, its time to accept other success criteria. *International Journal of Project Management*, *17*(6), 337–342. https://doi.org/10.1016/S0263-7863(98)00069-6

Babu, K. S., Raju, N. S., Reddy, M. S., & Rao, D. N. (2006). The material selection for typical wind turbine blades using a MADM approach & analysis of blades. *Multiple Criteria Decision Making (MCDM-2006)*, 1-12.

Baccarini, D. (1999). The Logical Framework Method for Defining Project Success. *Project Management Journal*, *30*(4), 25–32. https://doi.org/10.1177/875697289903000405

Badi, S., & Murtagh, N. (2019). Green supply chain management in construction: A systematic literature review and future research agenda. *Journal of Cleaner Production*, *223*, 312–322. https://doi.org/10.1016/j.jclepro.2019.03.132

Bal, M., Bryde, D., Fearon, D., & Ochieng, E. (2013). Stakeholder Engagement: Achieving Sustainability in the Construction Sector. *Sustainability (Switzerland)*, *5*(2), 695–710. https://doi.org/10.3390/su5020695

Baldwin, A., & Bordoli, D. (2014). *Handbook for construction planning and scheduling*. John Wiley & Sons.

Baumann, S., Erber, I., & Gattringer, M. (2016). Selection of risk identification instruments. *ACRN Oxford Journal of Finance and Risk Perspectives*, *5*, 27–41.

Belton, V., & Gear, T. (1983). On a short-coming of Saaty's method of analytic hierarchies. *Omega*, *11*(3), 228-230.

Boukezzoula, R., Galichet, S., & Foulloy, L. (2007). MIN and MAX operators for fuzzy intervals and their potential use in aggregation operators. *IEEE Transactions on Fuzzy Systems*, *15*(6), 1135–1144. https://doi.org/10.1109/TFUZZ.2006.890685

Bouyssou, D. (2009). Outranking Methods. *Encyclopedia of optimization*, *4*, 249-255.

Brammer, S., & Walker, H. (2011). Sustainable procurement in the public sector: An international comparative study. *International Journal of Operations and Production Management*, *31*(4), 452–476. https://doi.org/10.1108/01443571111119551

Brans, J. P., & Vincke, P. (1985). Note—A Preference Ranking Organisation Method. *Management Science*, *31*(6), 647–656. https://doi.org/10.1287/mnsc.31.6.647

Brans, J. P., Vincke, P., & Mareschal, B. (1986). How to select and how to rank projects: The Promethee method. *European Journal of Operational Research*, *24*(2), 228–238. https://doi.org/10.1016/0377-2217(86)90044-5

Chakraborty, S. (2011). Applications of the MOORA method for decision making in manufacturing environment. *International Journal of Advanced Manufacturing Technology*, *54*(9–12), 1155–1166. https://doi.org/10.1007/s00170-010-2972-0

Chan, A. P. C., Scott, D., & Chan, A. P. L. (2004). Factors Affecting the Success of a Construction Project. *Journal of Construction Engineering and Management*, *130*(1), 153–155. https://doi.org/10.1061/(asce)0733-9364(2004)130:1(153)

Charrel, P. J., & Galarreta, D. (2007). *Project management and risk management in complex projects*. Springer.

Charyton, C., Jagacinski, R. J., Merrill, J. A., Clifton, W., & DeDios, S. (2011). Assessing creativity specific to engineering with the revised Creative Engineering Design Assessment. *Journal of Engineering Education*, *100*(4), 778–799. https://doi.org/10.1002/j.2168-9830.2011.tb00036.x

Chen, C. T., Lin, C. T., & Huang, S. F. (2006). A fuzzy approach for supplier evaluation and selection in supply chain management. *International Journal of Production Economics*, *102*(2), 289–301. https://doi.org/10.1016/j.ijpe.2005.03.009

Cheung, F. K. T., Kuen, J. L. F., & Skitmore, M. (2002). Multi-criteria evaluation model for the selection of architectural consultants. *Construction Management and Economics*, *20*(7), 569–580. https://doi.org/10.1080/01446190210159818

Chinowsky, P. S., & Kingsley, G. A. (2009). An analysis of issues pertaining to Qualifications-Based Selection. In *American Council of Engineering Companies and American Public Works Association*.

Choudhry, R. M., Fang, D., & Ahmed, S. M. (2008). Safety management in construction: Best practices in Hong Kong. *Journal of Professional Issues in Engineering Education and Practice*, *134*(1), 20–32. https://doi.org/10.1061/(ASCE)1052-3928(2008)134:1(20)

Chow, L. K., & Ng, S. T. (2007). A fuzzy gap analysis model for evaluating the performance of engineering consultants. *Automation in Construction*, *16*(4), 425–435. https://doi.org/10.1016/j.autcon.2006.07.010

Christini, G., Fetsko, M., & Hendrickson, C. (2004). Environmental Management Systems and ISO 14001 Certification for Construction Firms. *Journal of Construction Engineering and Management*, *130*(3), 330–336. https://doi.org/10.1061/(asce)0733-9364(2004)130:3(330)

Christodoulou, S., Asce, A. M., Griffis, F. H. B., Asce, F., Barrett, L., & Okungbowa, M. (2004). *Qualifications-Based Selection of Professional A Õ E Services*. *20*(April), 34–41. https://doi.org/10.1061/(ASCE)0742-597X(2004)20

Day, E., & Barksdale, H. C. (1992). How firms select professional services. *Industrial Marketing Management*, *21*(2), 85–91. https://doi.org/10.1016/0019-8501(92)90002-B

De Boer, L., van der Wegen, L., & Telgen, J. (1998). Outranking methods in support of supplier selection. *European Journal of Purchasing and Supply Management*, *4*(2–3), 109–118. https://doi.org/10.1016/S0969-7012(97)00034-8

De Keyser, W., & Peeters, P. (1996). A note on the use of PROMETHEE multicriteria methods. *European journal of operational research*, *89*(3), 457-461.

Doloi, H. (2009). Analysis of pre-qualification criteria in contractor selection and their impacts on project success. *Construction Management and Economics*, *27*(12), 1245–1263. https://doi.org/10.1080/01446190903394541

Donabedian, A. (1981). Criteria, norms and standards of quality: What do they mean? *American Journal of Public Health*, *71*(4), 409–412. https://doi.org/10.2105/AJPH.71.4.409

Dubois, D., Prade, H., & Ughetto, L. (1999). Fuzzy logic, control engineering and artificial intelligence. In *Fuzzy Algorithms for control* (pp. 17-57). Springer, Dordrecht.

El Wardani, M. A., Messner, J. I., & Horman, M. J. (2006). Comparing Procurement Methods for Design-Build Projects. *Journal of Construction Engineering and Management*, *132*(3), 230–238. https://doi.org/10.1061/(asce)0733-9364(2006)132:3(230)

Fang, D., & Wu, H. (2013). Development of a Safety Culture Interaction (SCI) model for construction projects. *Safety Science*, *57*, 138–149. https://doi.org/10.1016/j.ssci.2013.02.003

Figueira, J., Greco, S., & Ehrgott, M. (2016). *Multiple criteria decision analysis: state of the art surveys*.

Figueira, J., Greco, S., Roy, B., & Słowiński, R. (2010). *ELECTRE Methods: Main Features and Recent Developments*. 51–89. https://doi.org/10.1007/978-3-540-92828-7_3

Findley, M., Smith, S., Kress, T., Petty, G., & Kim, E. (2004). Safety Program Elements in Construction. *Professional Safety*, *49*(2), 14–21. http://libproxy.unm.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=12136203&loginpage=Login.asp&scope=site

Fortes, J. (2009). Green supply chain management: A literature. *Otago Management Graduate Review*, *7*(1), 51-62.

Glantschnig, W. J. (1994). Green Design: An Introduction to Issues And Challenges. *IEEE Transactions on Components Packaging and Manufacturing Technology Part A*, *17*(4), 508–513. https://doi.org/10.1109/95.335033

Govindan, K., Shankar, K. M., & Kannan, D. (2016). Sustainable material selection for construction industry - A hybrid multi criteria decision making approach. *Renewable and Sustainable Energy Reviews*, *55*, 1274–1288. https://doi.org/10.1016/j.rser.2015.07.100

Gransberg, D. D., Molenaar, K. R., Scott, S., & Smith, N. (2007). Implementing best-value procurement in highway construction projects. *Alternative Project Delivery, Procurement, and Contracting Methods for Highways*, *January 2007*, 60–79. https://doi.org/10.1061/9780784408865.ch04

Green, K., Morton, B., & New, S. (1996). Purchasing and environmental management: interactions, policies and opportunities. *Business strategy and the environment*, *5*(3), 188-197.

Handfield, R. B., Melnyk, S. A., Calantone, R. J., & Curkovic, S. (2001). Integrating environmental concerns into the design process: The gap between theory and practice. *IEEE Transactions on Engineering Management*, *48*(2), 189–208. https://doi.org/10.1109/17.922478

Hidalgo, A., & Albors, J. (2008). Innovation management techniques and tools: A review from theory and practice. *R and D Management*, *38*(2), 113–127. https://doi.org/10.1111/j.1467-9310.2008.00503.x

Hollermann, S., Melzner, J., & Bargstädt, H. J. (2012). BIM - A challenge for communication between parties involved in construction. *EWork and EBusiness in Architecture, Engineering and Construction - Proceedings of the European Conference on Product and Process Modelling 2012, ECPPM 2012*, *August*, 833–838. https://doi.org/10.1201/b12516-132

Hormozi, A. M., & Dube, L. F. (1999). Establishing project control: Schedule, cost, and quality. *S.A.M. Advanced Management Journal*, *64*, 32. http://proquest.umi.com.library.capella.edu/pqdweb?did=47020102&Fmt=7&clientId=62763&RQT=309&VName=PQD

Hui, I. K., Chan, A. H. S., & Pun, K. F. (2001). Study of the Environmental Management System implementation practices. *Journal of Cleaner Production*, *9*(3), 269–276. https://doi.org/10.1016/S0959-6526(00)00061-5

Hwang, C. L., & Yoon, K. (1981). Methods for multiple attribute decision making. In *Multiple attribute decision making* (pp. 58-191). Springer, Berlin, Heidelberg.

İç, Y. T. (2012). An experimental design approach using TOPSIS method for the selection of computer-integrated manufacturing technologies. *Robotics and Computer-Integrated Manufacturing*, *28*(2), 245–256. https://doi.org/10.1016/j.rcim.2011.09.005

Jahanshahloo, G. R., Lotfi, F. H., & Izadikhah, M. (2006). An algorithmic method to extend TOPSIS for decision-making problems with interval data. *Applied Mathematics and Computation*, *175*(2), 1375–1384. https://doi.org/10.1016/j.amc.2005.08.048

Jazayeri, E., & Dadi, G. B. (2017). Construction Safety Management Systems and Methods of Safety Performance Measurement: A Review Health Monitoring of Bridges and Structures View project STRUCTURAL HEALTH MONITORING View project Construction Safety Management Systems and Methods of Safety Performance Measurement: A Review. *Journal of Safety Engineering*, *2017*(2), 15–28. https://doi.org/10.5923/j.safety.20170602.01

Jeong, H. W. (2009). *Conflict management and resolution: an introduction*. Routledge.

Jones, G. R., & George, J. M. (2015). *Contemporary Management, 9th edition*. McGraw Hill, New York.

Kabir, G., & Sumi, R. S. (2014). Integrating fuzzy analytic hierarchy process with PROMETHEE method for total quality management consultant selection. *Production and Manufacturing Research*, *2*(1), 380–399. https://doi.org/10.1080/21693277.2014.895689

Karakhan, A., Gambatese, J., & Rajendran, S. (2016). Application of choosing by advantages decision-making system to select fall-protection measures. *IGLC 2016 - 24th Annual Conference of the International Group for Lean Construction*, 33–42.

Kasma, D. R. (1987). Consultant selection. *Journal of Management in Engineering*, *3*(4), 288-296.

Kerzner, H. (2017). *Project management: a systems approach to planning, scheduling, and controlling*. John Wiley & Sons.

Kuchta, D. (2001). Use of fuzzy numbers in project risk (criticality) assessment. *International Journal of Project Management*, *19*(5), 305–310. https://doi.org/10.1016/S0263-7863(00)00022-3

Lember, V., Kalvet, T., & Kattel, R. (2011). Urban competitiveness and public procurement for innovation. *Urban Studies*, *48*(7), 1373–1395. https://doi.org/10.1177/0042098010374512

Lewis, J. P. (2011). *Project planning, scheduling & control*. McGraw-Hill.

Lines, B. C., & Shalwani, A. S. (2017). Best Value Procurement of Architectural and Engineering Services: Selection Characteristics and the Relative Influence of Various Evaluation Criteria. *AEI 2017: Resilience of the Integrated Building - Proceedings of the Architectural Engineering National Conference 2017*, *April*, 794–805. https://doi.org/10.1061/9780784480502.066

Ling, Y. Y. (2002). Model for Predicting Performance of Architects and Engineers. *Journal of Construction Engineering and Management*, *128*(5), 446–455. https://doi.org/10.1061/(asce)0733-9364(2002)128:5(446)

Ling, Y. Y., Ofori, G., & Low, S. P. (2003). Evaluation and Selection of Consultants for Design-Build Projects. *Project Management Journal*, *34*(1), 12–22. https://doi.org/10.1177/875697280303400103

Lo, W., Lin, C. L., & Yan, M. R. (2007). Contractor's Opportunistic Bidding Behavior and Equilibrium Price Level in the Construction Market. *Journal of Construction Engineering and Management*, *133*(6), 409–416. https://doi.org/10.1061/(asce)0733-9364(2007)133:6(409)

Lo, W., & Yan, M. R. (2009). Evaluating Qualification-Based Selection System: A Simulation Approach. *Journal of Construction Engineering and Management*, *135*(6), 458–465. https://doi.org/10.1061/(asce)co.1943-7862.0000013

Lucon, O., Ürge-Vorsatz, D., Ahmed, A. Z., Akbari, H., Bertoldi, P., Cabeza, L. F., ... & Vilariño, M. V. (2014). Buildings.

Macharis, C., Springael, J., De Brucker, K., & Verbeke, A. (2004). PROMETHEE and AHP: The design of operational synergies in multicriteria analysis - Strengthening PROMETHEE with ideas of AHP. *European Journal of Operational Research*, *153*(2), 307–317. https://doi.org/10.1016/S0377-2217(03)00153-X

Manoliadis, O. G., Pantouvakis, J. P., & Christodoulou, S. (2009). Improving qualifications-based selection by use of the fuzzy Delphi method. *Construction Management and Economics*, *27*(4), 373–384. https://doi.org/10.1080/01446190902758993

March, J. G. (1994). *Primer on decision making: How decisions happen*. Simon and Schuster.

Min, H., & Galle, W. P. (1997). Green Purchasing Strategies: Trends and Implications. *International Journal of Purchasing and Materials Management*, *33*(2), 10–17. https://doi.org/10.1111/j.1745-493x.1997.tb00026.x

Min, H., & Galle, W. P. (2001). Green purchasing practices of US firms. *International Journal of Operations and Production Management*, *21*(9), 1222–1238. https://doi.org/10.1108/EUM0000000005923

Ng, S. T., & Chow, L. K. (2004). Framework for evaluating the performance of engineering consultants. *Journal of Professional Issues in Engineering Education and Practice*, *130*(4), 280–288. https://doi.org/10.1061/(ASCE)1052-3928(2004)130:4(280)

Ng, S. T., & Skitmore, R. M. (1999). Client and consultant perspectives of prequalification criteria. *Building and Environment*, *34*(5), 607–621. https://doi.org/10.1016/S0360-1323(98)00050-X

Nofal, A., & Hammad, A. (2020). Application of fuzzy topsis for selecting most sustainable building wall material. *3rd European and Mediterranean Structural Engineering and Construction Conference 2020, Euro-Med-Sec 2020*, *Mcdm*, 1–6. https://doi.org/10.14455/ISEC.res.2020.7(1).CON-15

Ojo, E., Mbowa, C., & Akinlabi, E. (2014). Barriers in Implementing Green Supply Chain Management in Construction industry. *Iieom.Org*, 1974–1981. http://iieom.org/ieom2014/pdfs/432.pdf

Opricovic, S., & Tzeng, G. H. (2004). Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *European Journal of Operational Research*, *156*(2), 445–455. https://doi.org/10.1016/S0377-2217(03)00020-1

Papathanasiou, J., & Ploskas, N. (2018). Multiple criteria decision aid. In *Methods, Examples and Python Implementations, Vol. 136*. Springer Optimization and Its Applications.

Parrish, K., & Tommelein, I. (2009). Making design decisions using choosing by advantages. In *17th Annual Conference of the International Group for Lean Construction, IGLC17* (pp. 501-510).

Porter, M. E., & van der Linde, C. (1995). Green and competitive: ending the stalemate. *The Dynamics of the eco-efficient economy: environmental regulation and competitive advantage*, *33*.

Prause, D., & Mujtaba, B. G. (2015). Conflict Management Practices For Diverse Workplaces. *Journal of Business Studies Quarterly*, *6*(3), 13.

Princy, S., & Dhenakaran, S. S. (2016). Comparison of Triangular and Trapezoidal Fuzzy Membership Function. *Journal of Computer Science and Engineering*, *2*(8), 46–51.

Project Management Institute. (2013). *A guide to the Project Management Body of Knowledge (PMBOK guide)* (5th ed.). Newtown Square, Pennsylvania: Project Management Institute, Inc, pp.6, 533.

Pusca, D., & Northwood, D. O. (2016). Can lean principles be applied to course design in engineering education? *Global Journal of Engineering Education*, *18*(3), 173–179.

Rimmington, A., Dickens, G., & Pasquire, C. (2015). Impact of Information and Communication Technology (ICT) on construction projects. *Organization, Technology & Management in Construction: An International Journal*, *7*(3), 1367–1382. https://doi.org/10.5592/otmcj.2015.3.4

Roberts, D. W. (1986). Ordination on the basis of fuzzy set theory. *Vegetatio*, *66*(3), 123–131. https://doi.org/10.1007/BF00039905

Rollins, S. (2007). Qualification Based Selection (2007).

Rumane, A. R. (2010). *Quality management in construction projects*. Taylor & Francis.

Saaty, T. L. (1986). Axiomatic Foundation of the Analytic Hierarchy Process. *Management Science*, *32*(7), 841–855. https://doi.org/10.1287/mnsc.32.7.841

Saaty, T. L. (1996). *Decision making with dependence and feedback: The analytic network process* (Vol. 4922, No. 2). Pittsburgh: RWS publications.

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International journal of services sciences*, *1*(1), 83-98.

Saltelli, A., Tarantola, S., Campolongo, F., & Ratto, M. (2004). *Sensitivity analysis in practice: a guide to assessing scientific models* (Vol. 1). New York: Wiley.

Saremi, M., Mousavi, S. F., & Sanayei, A. (2009). TQM consultant selection in SMEs with TOPSIS under fuzzy environment. *Expert Systems with Applications*, *36*(2), 2742–2749. https://doi.org/10.1016/j.eswa.2008.01.034

Sawyer, J. T. (2014). *Qualifications Based Selection of Construction Services: Evaluation Criteria that Best Differentiate Contractor Qualifications*. Arizona State University.

Schöttle, A., Christensen, R., & Arroyo, P. (2019). Does choosing by advantages promote inclusiveness in group decision-making? *27th Annual Conference of the International*

Group for Lean Construction, IGLC 2019, *July*, 797–808. https://doi.org/10.24928/2019/0209

Sen, D. K., Datta, S., Patel, S. K., & Mahapatra, S. S. (2015). Multi-criteria decision making towards selection of industrial robot: Exploration of PROMETHEE II method. *Benchmarking*, *22*(3), 465–487. https://doi.org/10.1108/BIJ-05-2014-0046

Shen, L., Zhang, Z., & Zhang, X. (2017). Key factors affecting green procurement in real estate development: a China study. *Journal of Cleaner Production*, *153*, 372–383. https://doi.org/10.1016/j.jclepro.2016.02.021

Sporrong, J. (2011). Criteria in consultant selection: Public procurement of architectural and engineering services. *Australasian Journal of Construction Economics and Building*, *11*(4), 59–76. https://doi.org/10.5130/ajceb.v11i4.2297

Srivastava, S. K. (2007). Green supply-chain management: A state-of-the-art literature review. *International Journal of Management Reviews*, *9*(1), 53–80. https://doi.org/10.1111/j.1468-2370.2007.00202.x

Storteboom, A., Wondimu, P., Lohne, J., & Lædre, O. (2017). Best Value Procurement - The Practical Approach in the Netherlands. *Procedia Computer Science*, *121*, 398–406. https://doi.org/10.1016/j.procs.2017.11.054

Velasquez, M., & Hester, P. (2013). An analysis of multi-criteria decision making methods. *International Journal of Operations Research*, *10*(2), 56–66.

Vlad, I. (2018). Stakeholder checklist for priority-setting in low and middle-income countries. *F1000Research*, *7*.

Wang, L. C. (2008). Enhancing construction quality inspection and management using RFID technology. *Automation in Construction*, *17*(4), 467–479. https://doi.org/10.1016/j.autcon.2007.08.005

West, D. C. (1997). Purchasing Professional Services: The Case of Advertising Agencies. *International Journal of Purchasing and Materials Management*, *33*(2), 2–9. https://doi.org/10.1111/j.1745-493x.1997.tb00025.x

Wittstruck, D., & Teuteberg, F. (2012). Integrating the concept of sustainability into the partner selection process: A fuzzy-AHP-TOPSIS approach. *International Journal of Logistics Systems and Management*, *12*(2), 195–226. https://doi.org/10.1504/IJLSM.2012.047221

Wood, M. S., & Williams, D. W. (2014). Opportunity Evaluation as Rule-Based Decision Making. *Journal of Management Studies*, *51*(4), 573–602. https://doi.org/10.1111/joms.12018

Yang, J. B., Sen, P., & Meldrum, P. F. (1996). Multiple attribute evaluation in engineering decision support using limited compensation and reference designs. *Information and Systems Engineering*, *2*, 159-182.

Yu, W., & Wang, K.-W. (2012). Best Value or Lowest Bid? A Quantitative Perspective. *Journal of Construction Engineering and Management*, *138*(1), 128–134. https://doi.org/10.1061/(asce)co.1943-7862.0000414

Zadeh, L. A. (1988). Fuzzy logic. *Computer*, *21*(4), 83-93.

Zhu, Q., & Sarkis, J. (2004). Relationships between operational practices and performance among early adopters of green supply chain management practices in Chinese manufacturing enterprises. *Journal of Operations Management*, *22*(3), 265–289. https://doi.org/10.1016/j.jom.2004.01.005