Investigation of Forming a Framework to shortlist contractors in the tendering phase

التحقيق في تشكيل إطار عمل لاختيار المقاولين في مرحلة المناقصة

by

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ABSTRACT

The aim of this research is to create a framework that can predict the best contractor to be awarded a construction contract by a consultant/client using a different set of variables known as "Decision factors." This research was conducted to improve the traditional tendering process, the model was used to predict the "Success Rate" for the project by assessing each contractor's possibility of completing the project successfully using their compatibility with the project. The model creation was divided into multiple phases which started with finding the decision factors through an extensive literature review, and then determining the weights of each decision factor by conducting a survey that professional experts took. After obtaining the weights of the decision factors, a model using Machine Learning algorithm on Google Colab was written using the Python language. The model to shortlist contractors in the tendering phase was created using machine learning to enable more contractors to submit for a project without having to waste time and money on the tendering process; if they are compatible with the project, then they have a high chance of getting it by being short-listed for the project, which they can then submit their tender package for; this will also ensure that the best company gets the job for the client which will act as a great step towards improving the tendering in construction projects. For the consultant, it will decrease the load of going through numerous tender packages and ensuring that the best companies will tender for the project. This research has generated a base model that can be altered depending on the project requirements which can assist all parties involved within the tendering process to save time and money and improve the success rate of projects. The limitation of this research is that to use the framework to its full extent, it needs a huge database that includes data from numerous previous projects to be able to accurately predict the success rate of the upcoming project; however, if it could be regulated through governmental institutes then the database can be quickly collected within a relatively short period of time.

الهدف من هذا البحث هو إنشاء إطار عمل يمكنه توقع حصول أفضل مقاول على عقد بناء من قبل استشاري / عميل باستخدام مجموعة مختلفة من المتغيرات المعروفة باسم "عوامل القرار". تم إجراء هذا البحث لتحسين عملية تقديم العطاءات التقليدية ، حيث تم استخدام النموذج للتنبؤ بـ "معدل النجاح" للمشروع من خلال تقييم إمكانية كل مقاول لإتمام المشروع بنجاح باستخدام توافقه مع المشروع. تم تقسيم إنشاء النموذج إلى مراحل متعددة بدأت بإيجاد عوامل القرار من خلال مراجعة شاملة للأدبيات ، ثم تحديد أوزان كل عامل قرار من خلال إجراء استطلاع أجراه الخبراء المحترفون. بعد الحصول على أوزان عوامل القرار ، تمت كتابة نموذج باستخدام خوارزمية التعلم الآلي على Google Colab باستخدام لغة Python. تم إنشاء نموذج القائمة المختصرة للمقاولين في مرحلة المناقصة باستخدام التعلم الآلي لتمكين المزيد من المقاولين من التقدم لمشروع دون الحاجة إلى إضاعة الوقت والمال في عملية المناقصة ؛ إذا كانت متوافقة مع المشروع ، فإن لديهم فرصة كبيرة للحصول عليه من خلال القائمة المختصرة للمشروع ، والتي يمكنهم بعد ذلك تقديم حزمة العطاء الخاصة بهم ؛ سيضمن هذا أيضًا حصول أفضل شركة على الوظيفة للعميل والتي ستكون بمثابة خطوة كبيرة نحو تحسين العطاءات في مشاريع البناء. بالنسبة للاستشاري ، ستقلل من عبء المرور عبر حزم العطاءات العديدة والتأكد من أن أفضل الشركات ستقدم عطاءات للمشروع. أنتج هذا البحث نموذجًا أساسيًا يمكن تغييره وفقًا لمتطلبات المشروع والذي يمكن أن يساعد جميع الأطراف المشاركة في عملية المناقصة لتوفير الوقت والمال وتحسين معدل نجاح المشاريع. يحد هذا البحث من أنه لاستخدام إطار العمل إلى أقصى حد له ، فإنه يحتاج إلى قاعدة بيانات ضخمة تتضمن بيانات من العديد من المشاريع السابقة حتى يتمكن من التنبؤ بدقة بمعدل نجاح المشروع القادم ؛ ومع ذلك ، إذا كان من الممكن تنظيمها من خلال المؤسسات الحكومية ، فيمكن جمع قاعدة البيانات بسرعة خلال فترة زمنية قصيرة نسبيًا.

DEDICATION

I would like to dedicate this research to my beloved late father may ALLAH the Almighty dwell him in Jannatul Firdaus, you have always supported us and pushed us to be the best version of ourselves that we can be, and if ALLAH is willing we will be reunited in a better place.

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I would not have been able to finish this research nor would I have successfully completed my master's degree if not for the following people.

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My beloved mother who always ensured that I have my priorities in check and steered me into completing my Master's without delay, thank you for taking care of us; we love you. Even though we can never even come close to repaying a portion of what you did for us, we will try our best.

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My wife, my sunshine during dark times, the person that I find my tranquility in, I love you and would like to thank you for tolerating my ranting and technical discussions in the middle of the night with one eye open! Thank you for all the support you have given me, words cannot explain how much it means to me.

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CHAPTER ONE – INTRODUCTION

Background

The construction industry has been around for decades and is responsible for the growth of countries; a prime example is the United Arab Emirates, where construction was responsible for 10.3% in 2011 and reached 11.5% in 2021 of the country's gross domestic production (GDP) and is expected to grow even more (El-Sayegh, et al., 2020). However, the construction industry has been behind in adopting new technologies compared to the other sectors, which has decreased the advancement rate of the industry as a whole (Sepasgozar, Davis, Loosemore, & Bernold, 2018). A simple comparison is in the car manufacturing sector, which started decades after the construction industry. They achieved automated mass car production that still requires human labour but is just a fraction of what it used to. However, the construction industry is still extensively dependent on manual labour despite all the technological advancements; the construction industry has failed to adopt and adapt like the other industries. Especially since the fourth industrial revolution is around the corner, the construction industry needs to accept the available technologies and alter them to decrease time, decrease cost, improve quality, control risks, and improve safety levels (Aigbavboa & Thwala, 2020). That being said, due to the noticeable gap between the industries, there have been more researchers looking into the adoption of technologies in the field, such as Building Information Modeling (BIM), which brings the drawings to life by showing integrated details between the structural, architectural, and MEP drawings (Babič, Podbreznik, & Rebolj, 2010). BIM can even go to deeper levels by integrating environmental and cost analysis which resolves issues at early stages instead of finding out about them when it is too late (Babič, Podbreznik, & Rebolj, 2010). Other advancements being used are mass prefabrication, which saves cost and time; mass-producing joinery materials and façades, which dramatically reduces the time since the fabrication processes can finish by the time the site is ready for installation, which saves a lot of time and money. Moreover, recent studies have been using 3D printing technology to apply it to the construction industry such as 3D Concrete Printing Technology by Camillie Holt, and others (Holt, Edwards, Keyte, & Moghaddam, 2019). Tests have already been commenced on houses that eventually, once viable, can significantly decrease construction time and save money (Babič, Podbreznik, & Rebolj, 2010). Since the construction industry is behind in most aspects of projects, it is essential to begin developing the processes at the initial stages, such as the tendering process. If the project starts properly with more precise and clear requirements, the project will likely face fewer issues once commenced (Aapaoja, Kinnunen, & Haapasalo, 2013). It is important to fill the gap in knowledge and increase the information about the improvement of the tendering process which is an essential part in all construction projects.

1.0 Introduction

The construction industry is vast, and advancements in each sector are necessary for the industry to prosper. One of the most critical decisions is taken at the beginning of a project during the planning phase, which is selecting the contractor responsible for the execution of the work, which is done through a tendering process (Wong, Holt, & Cooper, 2010). Tendering is the process that awards the contract to a company through a sort of competition, which will be explained in the next section of this paper. Improving the tendering process dramatically improves the chances of success. Typically, the contract goes to the company that submitted the lowest bid after eliminating a few companies, even though numerous factors should be considered. However, given the time limitations that most projects must work under, companies rely heavily on data from previous projects, such as cost and time estimates, when planning the project (Wong, Holt, & Cooper, 2010). They prefer to work with companies with which they have had a good experience. However, that eliminates numerous other companies that would be a good fit for the new project; this is the case especially in fast-track projects, as time is of the essence, and the penalty of each day that the project is late costs the company a hefty amount (Smith, 1995).

Moreover, construction projects are very diverse, from infrastructure elements such as bridges, dams, and roads, to buildings, wastewater, and chemical plants, which is why numerous contractors are specialised in a specific field (Wong, Holt, & Harris, 2001). This specialisation should be taken into account during the tendering process to increase the chances of the project's success and to go more in depth, a contractor that works on small-scale projects is also different from a contractor that works on large-scale projects since each new project comes with its own set of problems and challenges that need to be faced, a company with the right experience does not just know how to deal with them but also anticipates the issues in advance which can turn them into opportunities (Laryea, 2010). These differentiations are critical for selecting a contractor; however, what is usually considered is the quality of their projects (conducted through a site visit of the company's most recent or ongoing project) and the price they bid. The price of the bid is, of course, to be taken as a significant part of the tender since, for most companies, a construction project is a significant investment that will have a substantial impact on the finances and success of the company as a whole, which is why all the factors mentioned, need to be balanced (Thomas, Cheung, Skitmore, & Wong, 2002). The balance usually depends on the expertise of the client because it does not matter how clear the drawings of a construction project are, which will be used in the tenders' misunderstandings and issues are bound to happen, which is why an experienced team from the contractor's side can identify them early on to decrease the number of issues and changes which will be faced later on (Abdul Rahman & Mermon, 2013).

In this research paper, an improved tendering process will be discussed to automate the processes using an algorithmic model to enable a higher number of applicants to go through the tendering process without increasing the workload on the client, which will ensure not only more viable options of contractors for the proposed project but also the most suited options by increasing the competition, resulting in a decrease in the chances of cost overruns and delays.

1.1 Traditional tendering process

There are differences between governmental and private sector projects in the tendering process as there are more constrictions on the governmental projects and how they award contracts. In this paper, the private sector projects will be discussed in detail, and the following are the steps of the traditional tendering process in detail, which was updated throughout the years but is still paper-based and takes a significant amount of time to complete due to its complexity (Rosmayati, Hamdan, Zulaiha, & Maizura, 2010).

1.1.1 Initiation of a project

After completing a project's business case, the client proceeds to initiate the project by signing the project charter. This phase is crucial to any project as it empowers the project manager who is officially assigned. The PM or the consultant is responsible for the subsequent processes, which are all coordinated with the client (Aapaoja, Kinnunen, & Haapasalo, 2013).

1.1.2 Tender specification preparation

The project documents are then prepared by the consultant, including the contract terms, Bill of Quantities (BOQ), drawings, and specifications. The consultant is also responsible for having an estimated time and cost of the project so they can be used as a reference.

1.1.2.1 Invite tenders

This process differs depending on the type and location of the project, but it is usually done in one of two different ways which are:

1.1.2.2 Open tender

As the name suggests, this method is open to everyone who is qualified and wants to participate, which increases the number of contractors and allows new contractors who have not worked with the client before to win the bid (Ritz, 1994).

1.1.2.3 Selected tender

In this method, the client invites a limited number of contractors to apply for the project. This method is used when companies with specific expertise are required for the project (only they can meet the required terms), have a good reputation, or have previously worked with the client or the consultant (Ritz, 1994).

1.1.3 Tender Enquiries

As the documents are usually lengthy and not everything is detailed, such as the drawings (which might have unclear information), the contractors’ team is bound to have questions that need to be clarified. To be entirely fair to everyone submitting a bid, any question a company asks needs to be broadcasted with clarification to all participants.

1.1.4 Reviewing the submitted tenders

This is the most important step in the tendering process, as selecting the right contractor can be the difference between success or project failure. The complexity of this step has numerous factors that need to be taken into account at the same time using expert judgement (accumulated knowledge from previous projects), which usually results in being biased toward companies that had a good experience with the client/ consultant in previous projects. In the open tender method, it is crucial to have a prequalification stage to ensure that the contractors who applied can in fact complete the project (they have the necessary resources needed) (Lenderink, Halman, & Boes, 2022).

1.1.5 Shortlisting and contract awarding

After the completion of the prequalification stage (if necessary), the contractors are then judged based on their qualifications (their previous projects' quality, their success rate since not all completed projects are successful), the compatibility between the contractor's qualifications and the complexity of the project, their technical capabilities, the resources available, and of course the time and money.

This is done to increase the project's success rate since a contractor with even a hundred percent success rate with small projects will face difficulties in a large project, and the opposite will lead to an expensive bid (Harty, et al., 2006-2007). This is because numerous elements change in a construction project between a small and a large project, which means it is not about increasing the manpower and time of the project. Even though the traditional method is outdated, due to the fact that it has been used for years, it was improved and enhanced to try and toggle as many issues as possible. However, having the tender documents paper-based ensures that it is a lengthy process, especially reviewing and shortlisting the contractors. Moreover, one-fifth of the contractors' operational revenue goes to tendering for new projects, and since tendering is manually done, mistakes are more frequent, negatively impacting the contractor's revenue (Harty, et al., 2006-2007).

1.2 Framework tendering process

With the current advancements in technology, it is possible to compare numerous documents in a concise duration if the proper comparison criteria are set, which allows a more significant number of contractors to be compared and automatically short-list the best options possible for the project, increasing the competition and increasing the chances of project success (Hatush & Skitmore, 1998). However, the difficulty in automated contracts is the lack of judgement which cannot be efficiently coded (Chan, Chiu, & Hung, 2007). In real-life projects, delays might occur for numerous reasons, such as the automated pre-tender questions that included a straightforward question about whether the contractor's previous projects were delayed. In that case, it will not incorporate the reasons behind the delay in the analysis, eliminating many contractors unfairly. The "if, then" system can be used instead of the "1s" and "0s" system to enable the tender to be more accurate and to incorporate the reason behind the issues that were faced. The "if, then" coding tool can get a close approximation to the actual reason for the project delay (Fullbright, 2016). Another option is using semi-automated processes to decrease the human workload of going through complete tenders, which will shorten the process without eliminating the human analysis. It becomes easier to code prices and timelines once the tender analysis starts since the code will be able to go through the same format created to sort the numbers submitted and analyse the raw data of the contractor to suggest the best contractor concerning time, cost, and quality (Clack, Bakshi, & Braine, 2017). One of the most important goals of smart contracts is to reach a level where it will clarify most disputes between the project parties that arise due to clarity of documentation, such as which party is responsible for an activity; such clarifications will be much more evident at an earlier stage of the project which will decrease issues once the project starts. To achieve an intelligent tendering process, it is important to use advanced software and refrain from using traditional methods such as paper documentation. Building Information Model (BIM) is a huge asset that needs to be incorporated in the early stages of the tendering process since it will facilitate the process of translating the paper documents as well as the 2D drawings that are usually used in the pricing of a project into simpler formats which will save time and money for the contractor (HMG, 2015). It will also ease the process of comparison between different tenders for the client. Moreover, after completing the tendering process, digitalizing all of the project's information eases the planning phase and decreases any misunderstandings throughout the project.

CHAPTER TWO – THEORTICAL BACKGROUND

2.1 Research Rationale

This research aims to fill the knowledge gap to enable the construction industry to improve the tendering process by using available technological advancements. This will decrease the cost and time associated with the traditional tendering process and increase the success rate of construction projects by ensuring that the best contractor is awarded the job.

2.2 Research questions

This investigation should answer the following research questions:

- How can the tendering process be improved in the current construction industry?
- How can the time of the tendering process be decreased?
- How will improving the tendering process impact the projects?

2.3 Research Aim

The project aims to improve the tendering process by filtering a higher number of contractors for each project and suggesting the best options that can complete the project within the required cost, time, and quality.

2.4 Research objectives

To achieve the aim of the project, the following objectives were completed:

1. To thoroughly examine the existing tendering process.
2. To determine how a framework will assist with the tendering process to save time and money for the concerned parties.
3. To create a framework that can be added to assist the tendering process in improving the project success rate.

2.5 Research Methodology

The following methodology was followed to ensure that the research objectives were achieved. First off, a complete background study was conducted to ensure that the existing construction industry tendering process situation is appropriately assessed. Secondly, an extensive literature review was conducted to confirm a knowledge gap in the construction industry regarding tendering process improvement. Moreover, the review also included another purpose: to find a set of criteria that can be used to rank the different categories of the contractor. After finding the categories called “Decision factors,” altering them to fit the project requirements was essential. The weights of each factor depend on the project priorities, which is why a survey was conducted to measure the importance of each decision factor and decide the weights of each in order to measure the “Success rate,” which will be considered as the ranking factor to compare different contractors. Afterwards, a model was created using the Python language on Google Colab based on Multi Linear Regression to predict the success rate and compare it to the manually computed success rate, which was based on the weights of each decision factor. The model kept being modified until a high accuracy in predictions was achieved. Figure 1 is a flow chart showing how the research was conducted in detail.

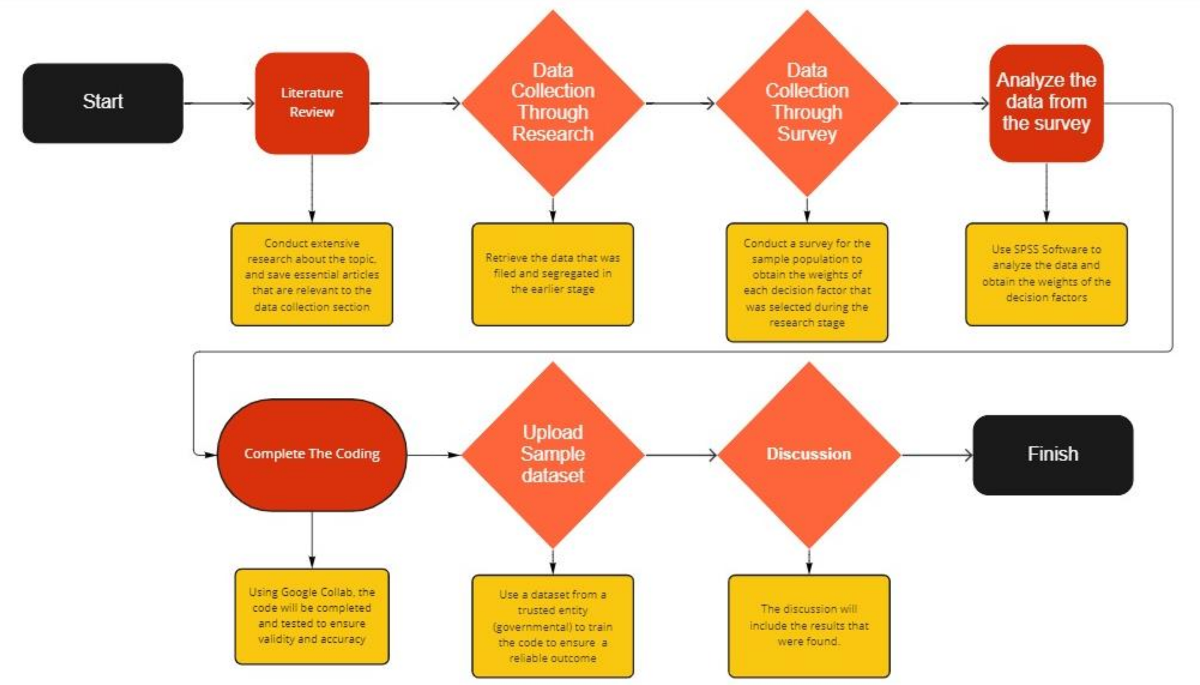

Figure 1: Research Approach

After completing the survey and the weights were decided, the Success rate for each contractor was computed using excel and the dataset, which was also uploaded to Google Colab to compare the computed success rate and the predicted success rate from the model created. The steps that were followed during the model creation are discussed in the discussion, including the analyzed data; however, Figure 2 shows the steps that were followed in a flow chart.

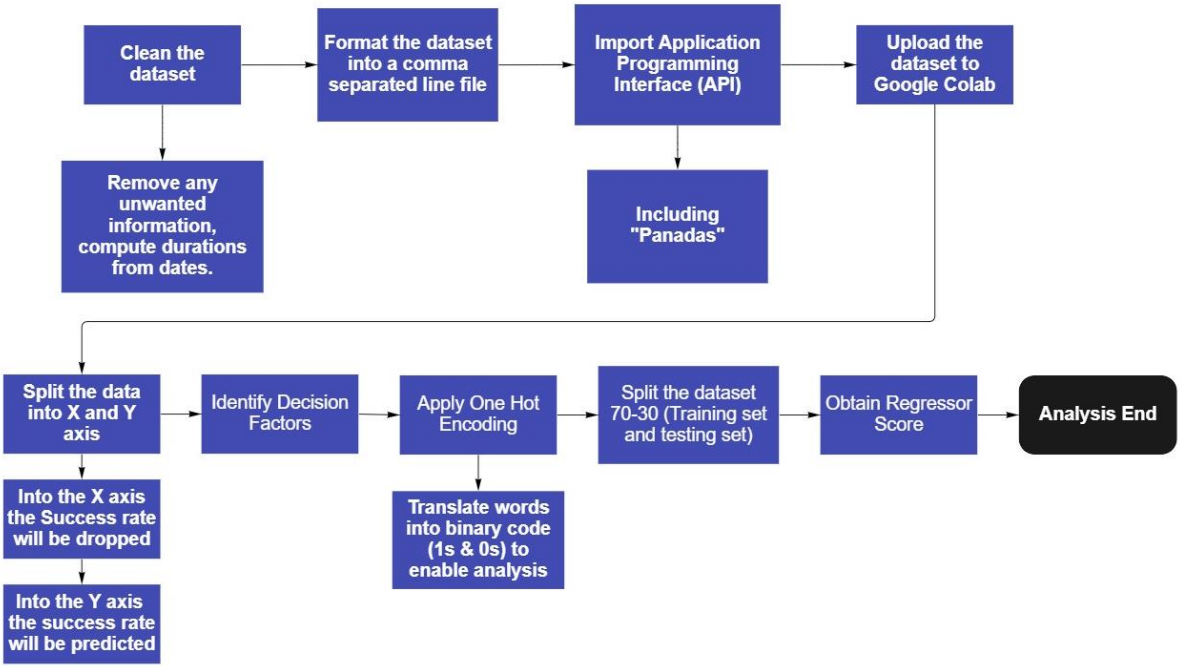

Figure 2: Model Approach

CHAPTER THREE – CONCEPTUAL FRAMEWORK

3.1 Literature review

The construction industry is one of the primary and vital fields that is essential for any country for its development and the benefits that it provides from creating buildings, improving societies, and providing jobs (Ofori2, 2015). However, within the construction industry, multiple challenges arise, starting from the releasing stage of the project (Stephen & Achim, 2004). Most construction projects are released through a tender which follows an award to a specific company to do the necessary work; however, the tendering stage consumes a long period of time which in some cases results in delay in project delivery or increased project costs that are commonly observed in open invitation tenders where a large number of contractors are participating (Jafari, 2013). Previously for the last 20 years, the dominant method for selection of the winning company was through considering the lowest bid procurement process; however, due to repeated situations of the incompetence of the winning company in performing the required scope of work of the project that process has been replaced by a prequalification stage (Jafari, 2013). Nowadays, the tender release starts with the tender announcement that allows companies to submit an expression of interest (EOI) in participating in this project. Following the EOI, the companies that have submitted their interest would need to submit their prequalification, which is later on evaluated based on a specific framework that is set that would result in a shortlisted number of companies of a maximum of five that would be invited to submit their bid for the tender. This stage of prequalification's allows for a more efficient tender process and reduces the cost that would arise from evaluating the numerous submissions for the tender (Mohemad, Razak, & Zulaiha Ali, 2014).

In addition, previously, the most common and essential decision-making was based on the cost-benefit analysis (CBA), which is pure price/cost-oriented; however, due to the multiple failed projects, this objective has been changed. The EU Directives implemented in 2004 two codifications of rules referring to procurement methods: Directives 2004/18/EC and 2004/17/EC (Marovic, Peric, & Hanak, 2021). These directives would guide the client to a different procurement approach that is a forward-looking way to achieve a more prosperous and sustainable project. This approach would consider a multi-criteria method based on several criteria points on which the bidders would be evaluated (Vidregor, 2016). However, since it is difficult to understand and cooperate with these different criteria points by the client, different models have been developed. These approaches need to consider the most technical aspects of the bidders, some of which also include the economic, social, environmental, and other aspects that would specifically be important as a long-term impact on a project's outcome (Akkerman, 2016). These aspects would increase the transparency between the client and the bidder concerning the project and allow for the incorporation of opposing stakeholders' demands which is usually the case for some projects. Another two advantages of the multi-decision criteria model (MDCM) is that it improves the legitimacy of the bidder and the final project outcome and provides excellent potential for its application in other similar complex decision-making problems that would also require a sustainable decision to be taken (Sadeghi-Niaraki, Kim, & Varshosaz, 2010).

The evaluation criteria that the client and consultant will set are as important as the whole process as every contractor has unique prequalification criteria that might not be observed or appreciated if the selection criteria do not address them (Adeleye, 2016). Therefore, clients should carefully outline and list the specific evaluation criteria for that specific project, which would be fair for all participants. There have been multiple proposed frameworks in the industry for shortlisting contractors in the tendering stage, 4 of which will be discussed in this literature review.

3.1.1 Analytical hierarchy process (AHP)

The analytical process that Saaty first developed uses hierarchy decomposition of various complex information in decision making based on set multicriteria such as the vendor registration information or production competence evaluation (Alamoudi & Balubaid, 2015). The analytical hierarchy process is a multiple criteria decision-making (MCDM) tool that is very flexible in that it can be integrated with different techniques such as quality function deployment and others (Wang et al., 2013). The AHP turns the qualitative criteria into quantitative indicators that can further be analyzed to help select the highest-scored bidders. The AHP is considered one of the most popular methods due to its simplicity and systematic organizing of tangible and intangible factors. In addition, the AHP depends on the decision-makers intuitive judgments and the evaluation process's consistency (Darko, et al., 2019).

One of the research articles completed a questionnaire with Saudi Aramco contracting department and the project management department to find out the AHP hierarchy model they would want to follow for the bidder's evaluation for a set project (Alamoudi & Balubaid, 2015). The result from the questionnaire has set 6 different criteria that include: financial capital, past performance, resources, current workload, past experience, and safety performance. Each criteria point is evaluated based on multiple indicators for the financial capability; the following indicators can be considered; return on net worth ratio, credit ratio, current ratio, asset turnover ratio, firm growth, and other indicators can also be considered (Alamoudi & Balubaid, 2015). The indicators differ from one criteria point to another; for instance, for the past experience, the indicators considered include the contractor's years in business, contractors' activity during the last three years, and the candidate's experience in similar projects, and that is all based on awarded projects and contracts (Alamoudi & Balubaid, 2015). These criteria might differ between one client and another and even one project to another, and such criteria are both project and client sensitive. Table 1 summarizes each bidder standing to the model criteria:

Table 1: Comparison Table of Bidders based on the AHP set Criteria Points (Alamoudi & Balubaid, 2015)

	Bidder 1	Bidder 2	Bidder 3
Financial Capability	$3 MM Assets	$3.5 MM Assets	$2.7 MM Assets
Past Performance	Below Average	Average	Above Average
Past Experience	No Similar Experience	Good Experience	Good Experience
Resources	Manpower of 700 with Direct Sponsorship	Manpower of 400 with Direct Sponsorship/400 to Be Mobilized Later	Manpower of 550 with Direct Sponsorship
Current Workload	5 Capital Projects at Various Locations	Two Capital Projects	One Large Project Nearing Completion, Two Capital Projects Underway
Safety Performance	Average	Average	Average

The above criteria points are then converted to a scoring system which is again converted to a normalized matrix and a pairwise comparison for each criterion. In the beginning, the consistency index is calculated using the below formula, which is based on the number of factors involved (n) and the average sum of each column for each bidder (lmax "Eigen value") (Amalia & Setyohadi, 2018). The method of calculating the Eigen vector is done through following the current procedure: "the division between the first line against the number of values in the first column of the second row in Add and divide the amount of the value of the second column and so on" (Amalia & Setyohadi, 2018). Based on the pairwise comparison table and by using the below formula.

$$CI= (\lambda_{max} – n)/(n-1)$$

The pairwise comparison is then generated from the CI calculation, and the above calculation can only be done if you have two or more bidders involved in the AHP calculation. Saaty, the creator of AHP, has described the pairwise comparison as the following "the element that appears in the left-hand column is always compared with the element appearing in the top row, and the value is given to the element in the column as it is compared with the element in the row (Fong & Choi, 2000). If it is regarded less favourably, the judgment is a fraction. The reciprocal value is entered in the position where the second element when it appears in the column, is compared with the first element when it appears in the row" (Fong & Choi, 2000). The consistency ratio is then calculated from the consistency index as per the below formula:

$$CR= CI/RI$$

This CR calculation considers the priority of each factor and the constant variable RI that is dependent on the number of criteria set. The constant value of RI is based on an nxn matrix which is pre-calculated using a computer simulation of random figures, considering a 1 to 9 scale (Alamoudi & Balubaid, 2015). The calculation of the CR formula for each bidder has generated Table 2:

Table 2: Priority Vector Results for Each Bidder based on the Consistency Ratio calculation set by the AHP Model (Alamoudi & Balubaid, 2015)

	Financial Capability	Past Performance	Past Experience	Resources	Current Workload	Safety Performance	Final Priority Vector
Bidder 1	0.416	0.354	0.309	0.323	0.512	0.555	0.390
Bidder 2	0.272	0.366	0.377	0.306	0.128	0.394	0.326
Bidder 3	0.312	0.280	0.314	0.371	0.360	0.394	0.285

Based on the above figures, it can be concluded that bidder 1 has the highest score and should be selected. This case study considered only three bidders; however, post EOI stage of a project announcement, the number of bidders that usually express interest in the project would cross 10; therefore, this method can help the client select only the top 5 bidders that have the highest score to submit their bid for the tender thus reducing the time and effort required for reviewing all 10+ bidder's bid submissions (Alamoudi & Balubaid, 2015). In addition, the above process can be automated and calculated efficiently using a program such as a machine learning model or MATLAB or any more straightforward program such as Excel, and all that the client would require is to review the final scoring.

Another benefit of AHP is that it is flexible in a way that it can be cooperated with other models and allows for group decision-making (Anagnostopoulos & Vavatsikos, 2006). Each group member can provide their own opinion on each criteria point, and then a joint decision is registered; however, if the group cannot come up with a unified decision, a certain voting technique can be followed. Other than the fact that AHP can be incorporated with other systems; however, it can also be used in tender submission evaluation and winning bidder selection, therefore not necessarily only prequalification evaluation (Anagnostopoulos & Vavatsikos, 2006). Hoseinpoor and Alborzi have conducted a sample case study using AHP with data envelopment analysis (DEA) for the selection of the winning bidder for a gas refinery project (Hoseinpoor & Alborzi, 2019). Based on the group analytical hierarchy process, the below table has been generated, and company 19 was found to have the highest score and was selected as the winning company for the project.

Figure 3: Contractors Priority based on the DEA and AHP models (Hoseinpoor & Alborzi, 2019)

Another research paper has conducted the AHP for ready-mix concrete (RMC) plant project for prequalification evaluation of the participating contractors that will conclude with the approved bidders that will be invited to submit their bid for this project (Belekar, Jamadar, Singh , Manjarekar, & Kazi, 2021). For this study, a 10-stepped methodology has been set for the AHP model, which includes the following: selection of criteria, preparation of survey form based on selected criteria, collection responses within the selected region, allotment of weights to the respective criteria, and RMC contractors, pairwise comparison of selected criteria's, pairwise comparison of RMC contractors for each selected criteria, calculation of priority vector for each criterion, calculation of consistency index and consistency ratio, calculation of overall priority for each RMC contractors, and finally the selection of the contractors based on the above process (Makwana, 2013). This methodology has been followed until the final table with the scoring system has been generated, which, accordingly, the highest score bidders have been approved for submission of their bid for this project (Makwana, 2013). As mentioned earlier, the methodology that has been followed in this project differs from one project to another based on the priorities that need to be considered for that specific project, or it can even be different between one client and another.

3.1.2 Analytical network process (ANP)

Previously discussed was the analytical hierarchy process; however, another model based on the multi-criteria decision-making model is the analytical network process which will be introduced and discussed in this section. Before applying the ANP, three main definitions need to be made that includes the demonstration of a clear context of the analysis, classification of the available options, and finally, making the decisions of the main objective of the selection based on the correct criteria that serve the benefit of making the correct final decision (Zare, et al., 2018). The ANP is also a mathematical theory developed in the 1970s and was developed by Thomas Saaty. It is based on identifying priorities of decision-making based on multiple variables without having to establish a hierarchical relationship between the decision levels (Zare, et al., 2018). ANP was, in fact, developed from AHP as a new and innovative approach that can help not only the practitioners in the industry but also the academics. The main difference between ANP and AHP is that AHP model is based on a hierarchy methodology with a set goal; however, ANP is based on a set structure that is based on a network (Cakmak & Cakmak, 2014). It can be observed from the below figures how the AHP general form is based on a hierarchy system; however, the ANP considers interdependences between the factors and creates a network system instead.

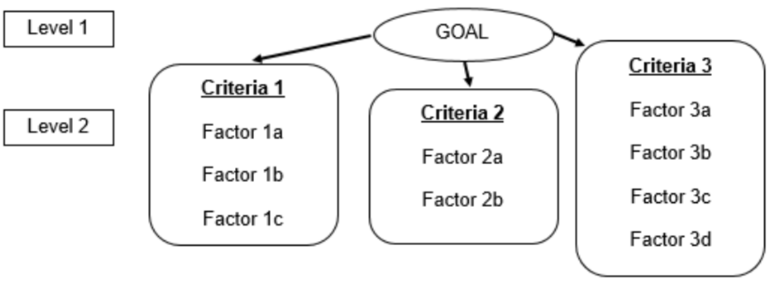

Figure 4: ANP General Form (Falamarzi , 2020)

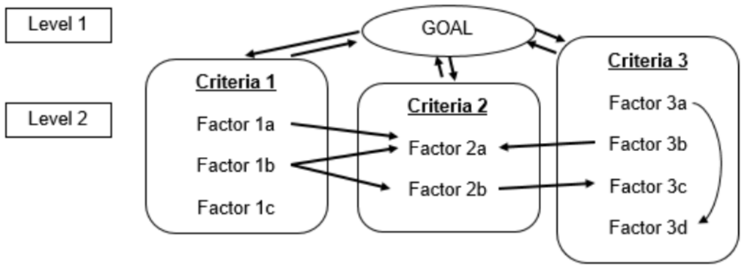

Figure 5: AHP General Form (Falamarzi , 2020)

The factors that will be considered in terms of criteria in an ANP system could be the same or similar to the ones considered in the AHP system, such as technical qualification, financial stability, past qualification, experience in related projects, and others (Falamarzi , 2020). Such criteria points will also include various indicators in determining the correct evaluation of these factors. In addition, the ideal way to apply an ANP is by following a certain methodology. A sample methodology that could be followed includes the following; firstly, to study the literature that includes the revision of the subject project to other related similar projects (Eshtehardian, Ghodousi, & Bejan, 2013). Secondly, the identification of the problem, which in this case is to identify the companies that would be interested in working on this project which would include the EOI stage. Thirdly, would be the data collection stage which includes the qualitative data, observations, and interviews. Fourthly and lastly is the actual calculation of converting the collected qualitative data into quantitative figures (Eshtehardian, Ghodousi, & Bejan, 2013). These calculations are similar to the ones followed in an AHP process that includes the pairwise comparison, the consistency index, and consistency ratio (CR) calculation. Finally, if the CR value is less than 0.1, then that would prove consistent data. Following this step, the Eigenvector is calculated for each to connect these criteria and generate a network (Lin, Wang, & Yu, 2008). After completing the Eigenvector calculation, a pairwise comparison matrix of the alternatives for each criteria point is done until it reaches a final ranking table. Each ANP model contains a square matrix that is generated by comparing each element opposite to the same element in the list (Zebardast, 2010). This comparison would show an element's dominance compared to its relative element of that specific list. It is in that specific matrix where the network between the different criteria is done in comparison to the AHP hierarchy system (Zebardast, 2010). The figure below represents a network's supermatrix, which is a detailed network between the criteria points that corresponds to the impact of the priority vector. The supermatrix mainly modifies the relative importance weights for each bidder matrices and thus forming a new overall matrix that also includes the Eigenvectors of the modified relative importance weights.

$$
W_{ij} = \begin{bmatrix} W_{i1}^{(j_1)} & W_{i1}^{(j_2)} & \cdots & W_{i1}^{(jn_j)} \\ W_{i2}^{(j_1)} & W_{i2}^{(j_2)} & \cdots & W_{i2}^{(jn_j)} \\ \vdots & \vdots & & \vdots \\ W_{in_i}^{(j_1)} & W_{in_i}^{(j_2)} & \cdots & W_{in_i}^{(jn_j)} \end{bmatrix}
$$

Figure 6: ANP Super Matrix Model (Mahdi, Heiza, & ElSheikh, 2018)

For instance, one of the research articles that has applied the ANP model in one of the market projects has completed the whole required calculation for the study. After finding the consistency ratio for each bidder, the following step for determining the value of the alternative has been applied to create a network and connection between the criteria points (Amalia & Setyohadi, 2018). Based on the value of the alternative study a recalculation has been done with a pairwise comparison matrix that is based on the alternatives and finally normalizing the figures to result with the final ranked table of all bidders such as the below:

Alternative	A	T	H	K	TOTAL	NORMAL	RANK
PT. X	0,33	0,26	0,4	0,33	1,33	0,33	2
PT. Y	0,33	0,66	0,4	0,33	1,73	0,43	1
PT. Z	0,33	0,08	0,2	0,33	0,94	0,24	3

Figure 7: Bidders ranking table based on ANP model (Amalia & Setyohadi, 2018)

ANP not only can be used for the evaluation of the bidders to shortlist them based on their prequalification, but it can also evaluate the participants in terms of risk perspective. For instance, in one of the research articles that has addressed this topic for an infrastructure project has set a different methodology approach for applying the ANP in which the first step would be risk identification followed by the development of the conceptual model, then gathering contractors' data and information and finally based on the above details the implementation of the ANP technique (Mahdi, Heiza, & ElSheikh, 2018). The above example reconfirms the concept of flexibility of the model in terms of ease of applying it to different situations during the bidders' evaluation stage. In addition, for this specific example, the criteria that have been selected are different from the typically seen criteria; for instance, it mainly addresses points regarding the project team and their strength in handling all kinds of risks expected in infrastructure projects. It also includes another criterion that addresses the availability of resources, sub-contractors, technical and technological capabilities, and many others (Mahdi, Heiza, & ElSheikh, 2018).

Another perspective of the flexibility of the ANP is that it can be used for all kinds of industries, as usually such models are used in the construction industry; however, a case study has been done on applying it for a telecommunication GSM mobile service tender that was happening in the Middle East (Kalanaki, 2013). This research article first addressed the main advantages of using the ANP model compared to the usual multi-criteria division models. Some of these advantages include the simplicity of the model that allows anyone in both a technical and managerial position to understand it. Secondly, the benefit of the model is that it allows for mixing and transforming qualitative factors into quantitative values that will help in decision-making. Lastly, the approach of making the judgments and evaluation of the bidders in which it is based on a decomposition approach with a lower percentage of decision-making errors compared to other models as per multiple research studies (Li & Wang, 2022). After stating the advantages of ANP, the required calculations for its model have been done, and the results that include both the final scoring and ranking of the participating bidders have been concluded. These results were also compared to another evaluating model, the TI Matrix, which was found to be an identical match in terms of ranking. In addition, a sensitivity analysis was also conducted to confirm that the end results are, in fact, stable and that the decision-making model is robust (Jin, Zhang, & Yuan, 2018).

As mentioned previously, clients or consultants sometimes avoid applying such models due to the required calculation, which, if required to be done manually with multiple bidders participating, would require such a long impractical time period. Therefore, multiple software has an inbuilt ANP model in which the end-user is just required to enter the preliminary data and the type of network required between the different criteria, and the software will run the complete calculation. The trial of using software for the ANP model has been tested in one of the research articles focusing on that aspect and using the Super Decision Software in their study (Mohamed & Majeed, 2016). The data that was required to be inputted into the software includes the main criteria the bidders will be evaluated on and the questionnaire for the pairwise comparison. Figure 8 below represents a snapshot of the software after inputting the criteria, mentioning the required network, and comparing them. The software will subsequently automatically run the required calculations, including the eigenvectors and CR calculation, and will give a complete table showing the results with ranking. Therefore, by using this software for the ANP model, the client has saved time and cost and has guaranteed results with the conclusion of the best bidders to select to invite for the project (Mohamed & Majeed, 2016).

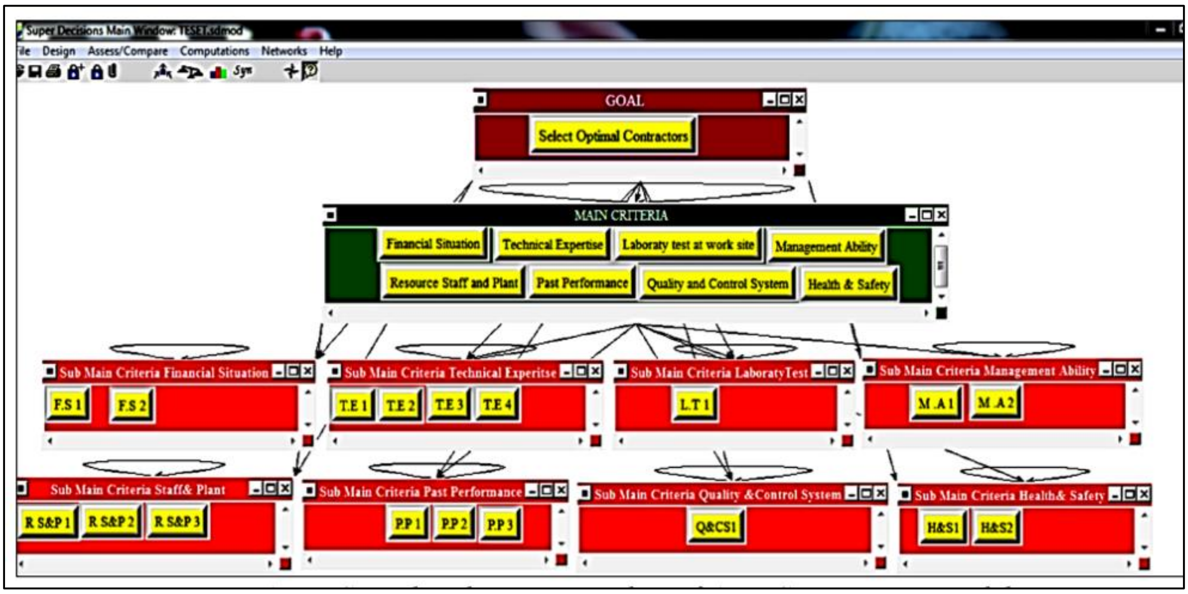

Figure 8: ANP Model using the Super Decision Software (Mohamed & Majeed, 2016)

3.1.3 Fuzzy Logic Approach

The third type of multi-criteria decision-making is the fuzzy logic introduced in 1965 by Zadeh and is a conceptual framework that represents the prequalification of bidders under uncertainty and imprecision but in terms of numerically based computing. The fuzzy logic is based on a bivalent logic that acts as a foundation between intelligent decision-making and software development that is portrayed in a true and false statement (Lapidus & Makarov, 2016). There are two sets of fuzzy logic; the first set is called type 1 fuzzy, which determines the relationship of an element but in terms of number in the range of [0,1]; however, in the case of uncertainty in a relationship the type 2 of fuzzy logic is deployed that addresses this uncertainty by a membership function. The below mathematical form represents the fuzzy logic type 1 in which the μA(x) represents the membership function that is run based on the limit that satisfies the xà [0,1] (Wu & Xu, 2021).

$$A = \{(x, \mu_A(x))|x \in X\}$$

However, type 2 of fuzzy logic is more complicated as observed from the below mathematical form of it since it accounts for uncertainty and ambiguity of the linguistic information that cannot be accounted for using type 1 (Wu & Xu, 2021).

$$\tilde{A} = ((x, u), \mu_{\tilde{A}})|\forall_x \in X, \forall_u \in J_x \leq [0,1]$$

The $\mu_{\tilde{A}}$ (x, u) is the type-1 fuzzy set; however, the Jx represents the primary membership degree of x and $\mu_{\tilde{A}}$ (x, u) which further goes into the secondary membership degree. For each primary membership degree a corresponding secondary membership degree is estimated in which the when $\mu_{\tilde{A}}$ (x, u) = 1, $\forall_u \in J_x \leq [0, 1]$, the relationship functions of this interval can be further derived with taking into consideration the ($\mu_{\tilde{A}}$) upper function membership that is and the ($\underline{\mu}_{\tilde{A}}$) lower function membership (Wu & Xu, 2021).

The above mathematical calculation of fuzzy logic is, in fact, one of the four components that a traditional fuzzy logic system consists of. These components include the fuzzification interface that is followed by a fuzzy rule base, then an inference engine, and finally, a defuzzification interface. The first step fuzzification interface consists of converting the linguistic input about each bidder to a fuzzy logic number based on the set of membership functions that will be considered (Hsieh, Lu, & Tzeng, 2004). Different types of membership functions can be used, including triangular, trapezoidal, Gaussian, generalized bell, and sigmoidal membership functions, each with its unique formula for calculation and estimation. The second step is the fuzzy rule base that includes the database, which contains all linguistic numbers statements and the fuzzy logic set of rules "criteria". Thirdly is the inference engine, which builds on the existing data of bidders from the database and extracts new knowledge based on the fuzzy rule base, and uses the AND & OR operation in the analysis. The fourth and last defuzzification step includes the extrapolation from the new set of data for each bidder based on the fuzzy logic points, which is a simple standard calculation of the mean of maximum or bisector of area or center of gravity (Khairuddin, Hasan, Hashmani, & Azam, 2021). This step will conclude the final scoring, and accordingly, the client or consulate can easily pick the highly qualified scored bidders and invite them for tender submission.

A fuzzy logic survey for contractor evaluation has been done in one of the research articles. The article has considered seven different criteria points as input variables to the fuzzy logic framework, and they include financial soundness, technical ability, management capability, resources, health, and safety. Reputation, and general suitability (El Agroudy , Elbeltagi, & El Razek, 2009). It can be noted that the input criteria are very similar between one evaluation method and the other; however, it's the calculation method and strategy that differs. The output variables from the fuzzy logic framework will include a classification of "Poor", "Good," and "Very good". The "Poor" & "Very Good" output variables have a trapezoidal membership function that covers the whole range of suitability of all contractors being evaluated, as mentioned above. In this research article, the software that was used for performing the required calculation, which consists of a fuzzy logic toolbox and is considered a user-friendly interface, is the MATLAB program. Based on the numerical based questionnaire results received from the contractors and the calculations that have been performed, the below table has been generated (El Agroudy , Elbeltagi, & El Razek, 2009.

Table 3: Contractors' Data Based on Fuzzy Logic Evaluation Method (El Agroudy , Elbeltagi, & El Razek, 2009)

Contractor	Financial Stability	Financial Soundness	Liquidity	Relevant Experience	Quality, time, cost	Coord. with owner/ consultant	Labor by trade skills	Past Failures	Price	Time	Quality
A	Stable	Good	75-100%	> 15	Good	Good	75-100%	< 10	> 1	> 1	V. Good
B	Medium stability	Good	0-25%	0-5	Good	Good	0-25%	10-30	> 1	= 1	Good
C	Medium stability	Good	25-75%	6-15	Good	Good	25-75%	10-30	< 1	= 1	Good
D	Stable	Good	25-75%	6-15	Good	Good	75-100%	< 10	> 1	= 1	V. Good

After generating the above table, one more step, which is clicking the bottom evaluate in MATLAB, will organize the above contractors in terms of highest-ranking percentage to the lowest, and accordingly, the consultant and/or the client can make their selection. In this study, only four contractors have been considered for the ease of the calculation. However, in a real case scenario, the end-user would have 20+ contractors that are interested in participating in a specific project, and this fuzzy logic method can help the contractor in reducing the number of contractors down to 5 and then accordingly review their bid submission.

Another research article has also run an evaluation case study for selecting contractors based on applying the fuzzy logic of an existing construction project in Turkey as it is considered as the most similar system to a human thought statement but represented mathematically in comparison to a human verbal statement (Akcay & Manisali, 2017). In this case study, 15 different input evaluation criteria variables have been selected, causing the evaluation to be even more competitive; for instance, some of the unusual criteria points that have been selected include the rate of unused cash credits amount to the offer price and the total own resources evaluation and others. In addition to the above criteria set points by the end-user; the client has also considered the EU Directive 2004/18/EC criteria points that include: price, quality, cost of operation and maintenance, term, technical support after construction, aesthetics, functional characteristics, and environmental characteristics (Bilgin, 2007). The fuzzy logic framework was also done using MATLAB software; however, using the centroid method is the preferred method for a clarification process. Based on running the operation of the model, the companies have been categorized into three groups from low profile, moderate profile, and high profile; and based on these results, the companies that have scored the highest ranking have been selected.

As mentioned previously, these multi-criteria decision models can also be combined to form a hybrid system, and one of the hybrid systems that are usually observed is the combination of fuzzy logic and AHP. The Fuzzy AHP, which is also known as FAHP is a model that is, in fact, based on the fuzzy set theory in which it is a membership function that would define a range between completely true and completely false. It would take into consideration the membership function in terms of criteria variables and alternatives; however, applied in a hierarchy concept with the main aim of the analysis is to compare the quality assurance in different contractor contracts, for instance, and might differ from one project to another. This method is commonly used when linguistic variables are common in the decision process as it would represent an expert judgment. All of the different membership functions can be used in the FAHP model; however, in a specific research article, the triangular membership function has been considered in order to evaluate the construction bidders that are willing to participate in the project (Lesnaik, Kubek, Plebankiewicz, Zima, & Belniak, 2018). Figure 10 represents how the calculation for FAHP follows, which would first start with the computation of the fuzzy values for each bidder based on the set criteria points. Secondly, a comparison of the degree of the possibilities in terms of alternatives will be commutated, and based on these possibilities, the least degree of a possibility is found, which is all based on a normalized property weight.

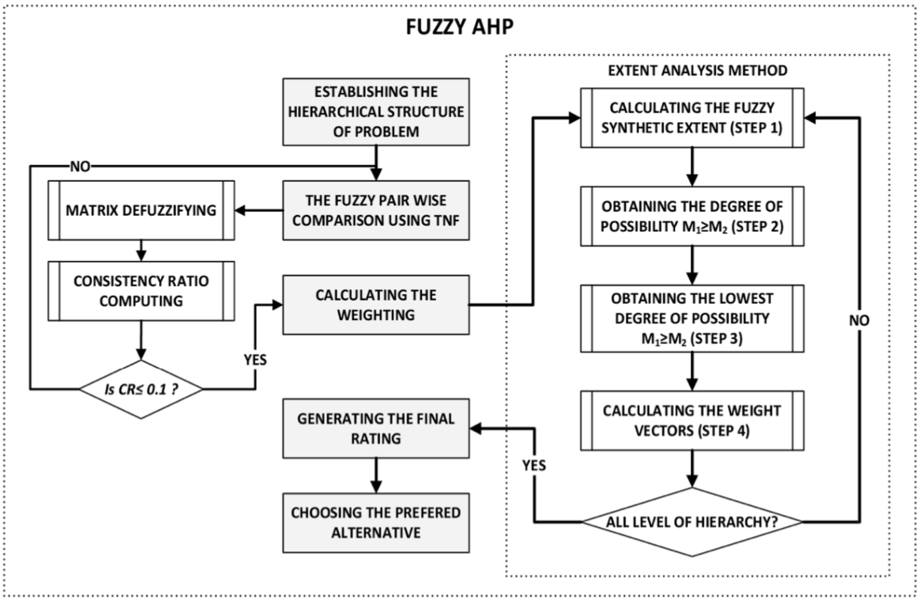

Figure 9: Fuzzy Analytic Hierarchy Process Flow Chart (Lesnaik, Kubek, Plebankiewicz, Zima, & Belniak, 2018).

The AHP final step of the consistency ratio still needs to be calculated and confirmed based on the random like matrix (RI) and the consistency index. The stage at which the AHP method is incorporated with the fuzzy logic method is after the consistency ratio calculation, in which the pairwise comparison matrix is defuzzified, and finally, the consistency evaluation is applied. In this article, the first step followed to obtain the details of the interested bidders is the questionnaire distributed to multiple personnel from each interested bidder. The main target for this evaluation is to find which of the 15 interested bidders are tender appropriate, and their submission for the tender should be allowed. In addition, to applying the FAHP a bid/no-bid decision analysis was also done to confirm the model's results. Another benefit of this model is that based on the scoring results, the most important criteria point can also be found, which in that specific research article was the financial capabilities of each bidder based on that specific project, and it could be set as the hierarchy criteria point of focus. Other models can be incorporated with fuzzy logic, such as VIKOR techniques; however, the FAHP is the most common method.

3.2 Qualification Based Selection

Qualification Based Selection (QBS) is the last multi-criteria decision-making method discussed in this literature review. The QBS differs from the methods mentioned above due to one specific point in which it takes into consideration the qualifications and competence of the bidders without considering the price or cost selection criteria and is also considered a dynamic method as it changes with the continuous changing the owners and clients demands in the marketplace. Because this method does not take into consideration any cost-related criteria points, it is referred to as the “pure QBS” in the 2004 edition of the AGC’s Project Delivery Systems for Construction (Qualifications Based Selection of Contractors, 2009). The QBS method is most commonly applied in architecture and engineering fields. There are various benefits for QBS; however, the main essence of it is that it creates a focus on quality and value in which all clients and end-users target a fully completed project based on a highly qualified company that works through teamwork and can demonstrate proactive behavior. In addition, QBS considers that these projects are not commodities but are a knowledge of services that this specific contracting company brings to it in a unique and valued manner. The selection basis of QBS is also based on multiple criteria since it is one of the MCDM models, and in addition to the two obvious criteria points, competence and qualification, other criteria points are also considered. These other criteria can include a company's experience and past performance, the capacity to perform a specific work, the safety plan and safety records for that company, the experience and past performance with the project delivery period, and many others. However, it cannot include any criteria related to price or cost, such as the cost of labor and working hours, and others.

The procedure of a QBS includes requesting a statement of qualification from the interested bidders in a specific project. These statements could include the company profile, registration, reference projects, recommendation letters from clients, and many others. Following the receipt of the statement of the qualification, the end-user evaluates the submission, and a set of shortlisted companies are selected based on the ranking, followed by an interview, and could also include a site visit of the location before the interview. The interview would discuss the project scope of work and the contractual point in which the bidder and the client would need to reach a mutual agreement. In this case, if that did not occur, this bidder would receive a lower score, and the following bidder would be considered. Based on the interviews, the client would select the best-ranked firms to participate in the project and submit their proposal. Another difference between QBS and the previous methods is that QBS is most commonly applied at the request of the proposal stage, unlike the other methods, which are also applied at the request of the proposal stage but are also commonly applied in the submission evaluation stage which is not the case for QBS.

One of the research articles discussed the main information required for the QBS model by distributing a survey to the American Public Works Association (APWA) members and the National Institute of Government Purchasing (NIGP) members (Qiao & Cummings, 2003). Multiple criteria point has been considered in the survey; however, based on the APWA results, the highest-ranked most important information was the bidder's ability to perform a function which was 96.6% of the answer, followed by the experience of its staff, which was 90.9% of the answers. The NIGP results were more equally distributed between the criteria points in comparison to APWA, in which the highest scored information, which was 85.5% of the answers, was also the bidder's ability to perform a function; however, it was followed by two equal results answers of 84.3% that are for the experience of the company and the company's references. It can be observed from the previous survey that these multiple criteria points differ from one client to another and how hybrid and dynamic the QBS model can be as it can dynamically change the client's requirement.

Another extremely important observation that also indicates a major difference between the QBS model and the previous model is that even though the QBS model is an MCDM however, it is not a numerically based process as it does not have any specific equations to follow and to calculate; however, is based on a statement of qualification that is reviewed and ranked by the client. This fact makes it difficult for this model to be combined or cooperated with other models; however, it would be considered a model that can only be used on its own. Another aspect that is also considered a disadvantage in this model is that it is highly dependent on the client; the client needs to evaluate this statement of qualifications one by one and put their ranking and, following that, perform the site visit and interviews. These procedures are not required in the other models as the results from the questionnaire can be inputted into a mathematical software that would run the required calculation, and based on the resulting ranking, the client would then select the bidders that will be allowed to participate in the project. In addition, the previous model results can be verified using other models; however, that will not be possible with the QBS model. Therefore, even though the QBS model is considered a simpler model to follow; however, it is a time-consuming process that is highly dependent on the client, which is a factor that clients do not usually have.

MDCM can also be applied to other bidder's evaluation objectives, and an example of an alternative object is the application of MDCM in the identification of unbalanced bidding. Unbalanced bidding refers to when the bidder would change the prices of a line item in a project bill of quantities in which they would increase the price of a couple of line items and alternatively decrease the price from other lines times which eventually would result in the same total constant price of the overall project. One of the research articles has reviewed that specific aspect by using the VIKOR approach, which was not discussed in this literature review since it is considered the main approach that is usually used for the identification of unbalanced bidding, which is usually the stage after bid submission. In contrast, the research focus is before the bid submission and at the stage of the bidder's invitation for proposal submission (Su, Wang, Li, Cao, & Wang, 2020). The reason behind the VIKOR approach being specific to unbalanced bidding is that it would consider the bidders' quotes and the single bidder's quote simultaneously, which would eventually result in a more reasonable outcome for the client. These different quotes act as multiple criteria points for evaluating other quotes. This research article runs the sensitivity calculation analysis of the VIKOR method using Microsoft Excel, in which the sensitivity value has presented to the client and the bidders whose quotes fall outside the range of balanced bids based on the maximum group utility.

Overall, all of the above-mentioned models are MCDM models, which would evaluate bidders fairly, especially considering that they are being evaluated based on multiple criteria points. The model selection that needs to be applied is based on client preference and the stage that this evaluation is applied. However, the different benefits of applying these models can be noted regardless of the selected model. As they can save time for the client, they would only evaluate the already prequalified bidders instead of evaluating all of the bidder's submissions. In addition, this time is considered as cost as the key in all of these projects; specifically, the construction projects are the delivery as any delay in project execution or delivery will result in cost impacts which all can be avoided by applying these models to meet and invite only the qualified bidders that would perform the required scope of work without any errors or mistakes and if any then at the very minimum.

CHAPTER FOUR – DATA

4.1 Introduction:

The data obtained for the investigation were collected in different stages; at first, it was crucial to have a starting point or a baseline for the research, which was a study conducted by two members of the American Society of Civil Engineers (ASCE) back in 1990 to create prequalification criteria for the contractors prior to starting a project to ensure that the contractor selected is the best fit for the project (Russell & Skibniewski, 1990). After obtaining the baseline model, newer research was used to ensure that the technologies developed since then are also accounted for in the new model. Finally, to ensure that the model works, a survey was created and sent out to different organizations within the field to gather primary data and ensure that the selected criteria are up to date and will incorporate all of the required criteria.

4.2 Baseline Model

The baseline model was created on IBM's computer manufactured in the 1980s, making it completely outdated compared to the current technology. However, the raw data obtained was then updated with newer research which will be discussed in the following section. In the Qualifier model (baseline model), factors were divided into two categories decision factors and decision sub-factors. A total of 20 decision factors and 67 sub-factors were included in the study; the below figure shows the 20 primary factors, which are all still valid.

Financial Stability
Experience
References
Past Performance
Capacity of Firm
Current Work Load
Project Control Procedures
Staff Available
Location of Home Office
Experience in Geographic Location of Project
Safety Performance
Substance Abuse Policy
Project Management Capabilities
Quality Performance
Manpower Resources (Labor)
Company Organization
Amount of Work Performed With Own Forces
Contractor Has Failed to Complete a Contract
Equipment Resources
Bonding Capacity

Decision Factors Listed in Questionnaire

Figure 10: Decision Factors (Russell & Skibniewski, 1990)

4.3 Selected Decision Factors

The study that was used to select the decision factors was conducted by Jeffery Russel and Miroslaw Skibniewski back in 1990; since then, it has been cited in numerous research papers and recent ones such as “Using the ISM Method to Analyse the Relationships between Various Contractor Prequalification Criteria" By Vincent Yu and others, and "A multi-criteria model to select candidates for public contracting using the OPTIONCARDS method" by Luís Valadares Tavares and Pedro Arruda. Both papers are about improving the contractor's selection process. The Decision Factors were selected because each one affects the project, and the more the contractor's qualifications fit the project, the higher the success rate and profit margin. Each decision factor will be discussed in detail, along with the frequencies obtained from the surveys in the discussion section.

The sub-factors are divisions of the decision factors which will also be ranked, as can be shown in table 3.

Table 4: Sub-factors (Russell & Skibniewski, 1990)

Parameter name (1)	Mean impact[b] (2)	Decision[c] factor weight (3)
(*a*) Composite factor 1. (Performance)		
Record of failure on past projects	3.42	0.18
Past performance	3.26	0.17
Quality performance	3.01	0.16
Project management capabilities	2.65	0.14
Staff available	2.35	0.13
Control procedures over work performed	2.25	0.12
Safety performance	1.86	0.10

The impact scale was 1-4, where 4 is the highest impact, one is the lowest, and the total sum of the sub-factors weight is 1 for each main factor to ensure that all decision factors are treated equally, as shown in the performance decision factor shown in the above table. The questionnaire revealed that public and Private owners have different preferences regarding decision factors, which is why it is important to weigh the factors based on the owner. A model was created based on the data that was gathered to rate the prequalification of contractors that depends on the type of owner for the project and the qualifications of the contractor (Russell & Skibniewski, 1990). This model was the baseline for the framework since it even allowed users to add/delete to the existing factors, but since it was old, new software and technologies needed to be incorporated, which is why more recent studies were also taken into account.

4.4 Recent data

Researching the most recent studies was crucial to ensure that the framework includes updated data since technology has significantly improved in the last few decades, which is why more recent studies than the baseline model needed to be taken into account. An article examining two decades regarding contractor selection was a huge asset to the data collection as numerous journals, and published articles were considered, as shown in Table 5.

Table 5: Results of searches (Holt, 2010)

Source/database	No. papers returned from search[a]	No. papers relevant to study[b]
ASCE Database http://pubs.asce.org/research/	86	24
Building and Environment www.sciencedirect.com/science/journal/03601323 ISSN: 0360-1323 (print)	133	13
Building Research and Information www.tandf.co.uk/journals/rbri ISSN: 0961-3218 (print)	35	6
Construction Management and Economics www.tandf.co.uk/journals/titles/01446193.html ISSN: 0144-6193 (print)	121	14
Construction Innovation http://info.emeraldinsight.com/products/journals/journals.htm?id=CI ISSN: 1471-4175 (print)	8	2
Engineering, Construction and Architectural Management http://info.emeraldinsight.com/products/journals/journals.htm?id=ecam ISSN: 0969-9988 (print)	164	10
International Journal of Project Management www.sciencedirect.com/science/journal/02637863 ISSN: 0263-7863 (print)	312	12
Other, non-specified journals		12
Total		93

Notes: [a]Using search terms "Contractor + Selection"; [b]subjectively chosen – refer to narrative

Reviewing the studies showed numerous ways to classify and select a contractor, such as private and public sectors needing to be treated differently (Khosrowshahi, 1999). Some studies studied the "best value" and showed that it should concentrate on the overall cost, including cost after the project (for example, earlier maintenance if the contractor would deliver poor quality) (Phillips, Dainty, & Price, 2007), and some researchers concentrated their studies based on specific countries and cities such as Lai who studied the case in China (Lai, Liu, & Wang, 2004), the study in Honk Kong which includes details to that specific region in China (Kumaraswamy, 1996). Others classified the selection based on the type of jobs, such as whether they are buildings, infrastructure, or maintenance projects. However, 60 percent of the studies agreed that a statistical model is the most beneficial way to classify contractors properly.

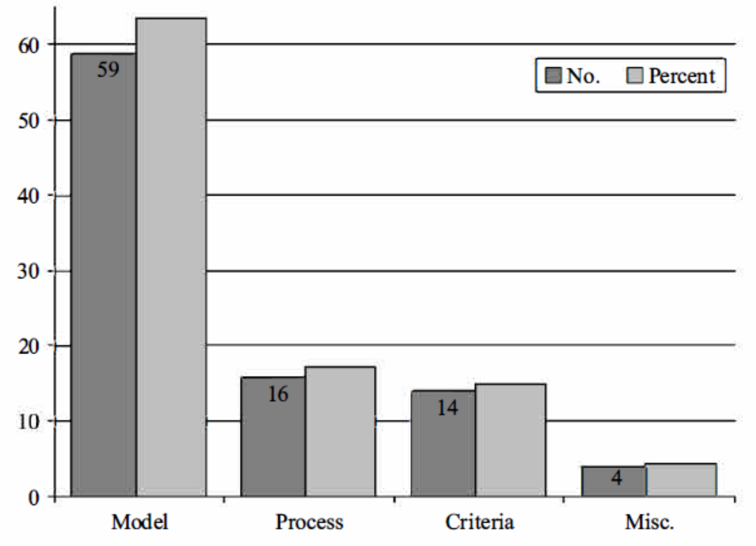

Figure 11: Classifications of research methods (Holt, 2010)

Figure 12 shows the different types of methods that were used to conduct the studies. A statistical model is used to analyze data to understand better the raw numbers (Legay, Delahaye, & Bensalem, 2010). Process means that the researchers took an existing study and modified it. Criteria are having a set of important metrics, and the contractors would qualify or not based on them. In comparison, the last four percent are under the classification of "miscellaneous" since they are different from these three main classifications (Holt, 2010). The data obtained from this research resulted in more profound research that was used to decide on the method that will be used for the framework, and it seemed clear that it also needed to enable users to configure their criteria since each location/ country has a different system that they abide by and each project has different priorities. However, for the sake of the research, a set of criteria will be presented based on the projects of the United States from a governmental website with trusted statistical data.

4.5 Practical considerations

The database needs to be created to reach a level where this framework can be integrated into construction projects regularly that allows clients to select a contractor that fits the project requirements easily. It is not easy to collect the data for all of the contractors in a country which is why it will be built with time by taking each new project that is initiated and assessing the capabilities of the contractors submitting to it at the time of the tendering process. During each project, and most importantly at the end of each project, feedback will be submitted to update the database, whether the project succeeded or failed, what has gone wrong, and what could have been improved. This allows the database to always be up to date, and with each iteration, it becomes more accurate, which is why it is crucial for the framework to be more user-friendly as it benefits all parties involved; the client to select the best contractor for the project at hand, the contractor to gain new projects with new clients, and even feedback on what went right/wrong from the point of view of the consultant/client. The update will include the same rating of the decision factor at that time, such as what phase is the project in at that specific time (time-frame), the cost that has been paid so far, quality, safety, and so on.

4.6 Methods of data collection

A survey to conclude the ratings of each decision factor had to be completed to ensure that the weights of each factor are relevant to real life. The survey was created and distributed to experts within the field. The survey was divided into three parts to separate the different sections which are included in the survey, which are:

1. Demographics: This includes information about the person taking the survey to ensure that the population targeted is properly represented.
2. Commercial Decision Factors: This includes the factors that depend on the commercial side of a project, such as the cost and time frame of projects with respect to the contractor that is being rated, such as did he have cost overrun, did he finish the project within the time frame, and how was his financial stability to ensure that the company is able to complete the coming project.
3. Technical Decision Factors: This includes factors such as the overall previous performance, quality, safety, and knowledge to complete the project to determine the technical capabilities of the company to ensure it can complete the coming project.

The sections of the survey were divided to properly classify the answers depending on the demographics of the survey takers, and then separate the commercial from the technical decision factors to understand the how each group rates the decision factors which will help in understanding the results of the survey (Kelley, Clark, Brown, & S., 2003). After the survey was created, it was distributed to experts within the field from different disciplines and positions on the managerial chain to represent the targeted population as accurately as possible without any bias.

4.6.1 Questionnaire Structure

As previously mentioned here are the three aspects of the Questionnaire:

Table 6: Survey Demographics Questions

Demographics						
Please answer the following Questions or leave the question blank if you do not which to disclose the information						
Gender	Male			Female		
Age	18-20	21-30	31-40	41-50	51-60	61+
Educational Background	High school	Diploma	Bachelor's or equivalent level	Master's or equivalent level	Doctoral or equivalent level	
Discipline	Concept	Design	Execution	Management	Structural	Others
Position in your company	Researcher	Junior	Middle Level	Managerial	Executive	
Years of Experience	0-2	3-5	6-10	11-15	16-20	21+

It is very important to understand the different personnel levels and backgrounds of those who are taking the survey to ensure that the weights of the decision factors are relevant. Even though usually managerial positions and above take the final decision about awarding the contractor a contract, it is important to gather as much data as possible, even from lower positions to ensure that we have a non-biased data set since it is possible that managers only look at the cost and time, whereas, middle levels might concentrate on the quality more. This is just an example of why it is important to have data beyond the level of decision makers.

Table 7: Survey Commercial Questions

To what extent do you agree/disagree with the following decision factors relevance to rating a contractor before the tendering phase						
Decision Factors	Strongly Agree	Agre e	Neutra l	Disagre e	Strongly Disagree	Don't know
Commercial						
Cost						
Time-frame						
Financial Stability						

Most projects aim to obtain the highest attainable return on investment, which is why the commercial aspect of a project is very important since completing the project within budget and on time greatly affects the return on investment. Within the construction contract, there is always a clause stating that if the project is delayed, then a penalty would apply to the contractor since each day after the initial completion day, the client would be decreasing the amount of his return and losing credibility from his investors/ clients.

Table 8: Technical Survey Questions

To what extent do you agree/disagree with the following decision factors relevance to rating a contractor before the tendering phase						
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Don't know
Technical						
Past Performance						
Quality rating of previous projects						
Completed similar project scale						
Safety ratings						
References						
Availability of staff for the project						
Equipment resources						
Relevant Experience						

The technical questions of the survey are intended to obtain an idea about which part of the project requirements are important, whether it is the quality, experience, capability, and other factors. This is important to ensure that the weights of the decision factors properly represent the right percentage of importance to each aspect of a contractor. If the survey shows that the most important part of a project is previous knowledge, then it would be important for the contractor that is tendering to a project to have completed a similar project in the past, and if he did not, then he would be ranked lower than others who did.

This survey will depend on experts' knowledge within the field in general since a specific project is not being taken into consideration for the sake of this research paper; however, future surveys will depend on a specific project that will be tendered to alter the weights of the decision factors of that project. It is important to note that the weights of the decision factors are not fixed, and they differ from one project to another since one project's most important aspect to be is the quality and another is the time frame. The decision factors need to be changed depending on the requirement of the project at hand.

4.6.2 Sampling strategy and data gathering

The following steps were taken to ensure proper representation of the intended population since it is not achievable to get the entire population to give their input:

1) Choosing the intended population: This was the first step in the process to get a general idea about who are the prime targets of the survey to properly represent the population, which are people with relevant experience in the field, with sufficient knowledge about the subject of selecting a contractor, and required information about the necessities of a project.
2) Checking the number of people required sample size to properly represent the population:

   Using the following equation, the sample size was deduced.

Equation 1: Sample Size Equation

$$\text{Unlimited population:} \quad n = \frac{z^2 \times \hat{p}(1-\hat{p})}{\varepsilon^2}$$

$$\text{Finite population:} \quad n' = \frac{n}{1 + \frac{z^2 \times \hat{p}(1-\hat{p})}{\varepsilon^2 N}}$$

where
z is the z score
ε is the margin of error
N is the population size
p̂ is the population proportion

   The unlimited population equation was used to find the required number for the sample size; where:

   Z that was used was 80% as the confidence level, the Margin of Error was 6%, the population proportion was 50%, and the result was 114.

   This means that 114 people are required to answer the given survey with a confidence level of 80%, and the actual value will be within the measured by ±6%.

3) Accessibility of the population: The accessibility of the population was challenging since a lot of managerial positions were required since they are the ones who usually take the decision when it comes to awarding contracts. Since 114 people were required, a total of 140 people were sent the survey expecting that not everyone would answer. However, only 103 surveys' were returned by the survey takers even after following up on the ones who did not reply.

4) The eligibility criteria of the survey takers were one of the restrictions that limited the number of people who were invited since the criteria were people with relevant experience and preferably decision makers, which is why only access to 140 people within the field was available.

The survey was created on an online platform that enables the data to be saved automatically as an SAV file to ease and ensure accurate data transfer, which can be used in SPSS software for statistical analysis. The survey questions have been added to Appendix A to show the questions that the participants answered.

CHAPTER FIVE – DATA ANALYSIS

5 Data analysis and discussion

The next step after obtaining the data was to start the analysis process, SPSS Statistics software was used for this step.

5.1 Demographics

5.1.1 Gender

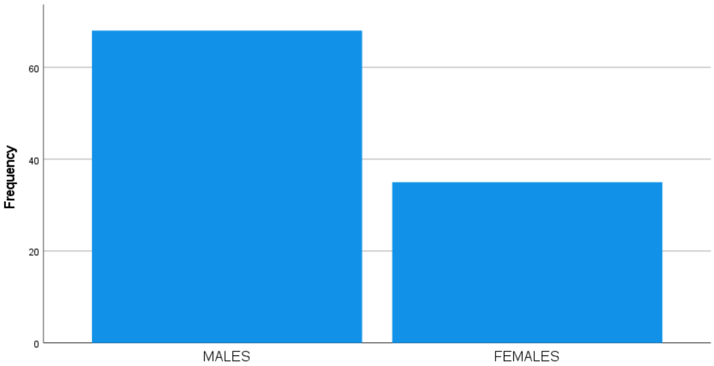

Figure 12: Genders of the Survey Takers

The ratio of males to females within the survey is almost 2/1 since the construction industry in the Middle East is more male-dominated; a total of 68 males and 35 have participated in the survey.

5.1.2 Age

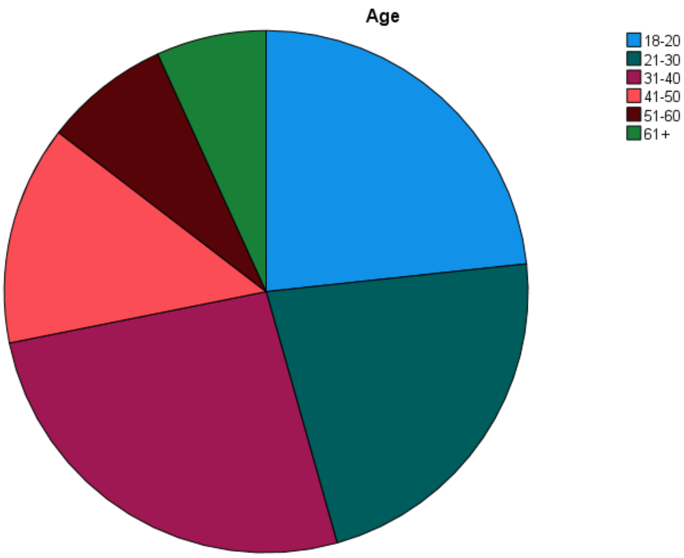

Figure 13: Age of Survey Participants

The majority of the participants' ages are between 31-40, with a percentage of 26%, 23% of 18-20, and 22% of 21-30.

5.1.3 Highest Educational Degree

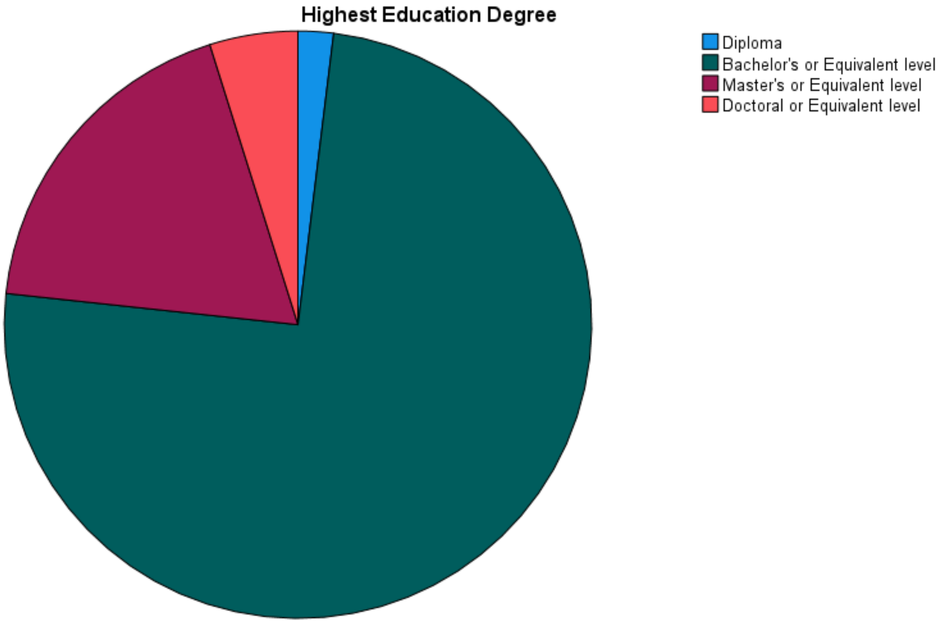

Figure 14: Highest Degree of the Survey Participants

As shown from the pie graph, most survey takers have a bachelor's degree as the highest educational background, followed by a Master's degree.

5.1.4 Field

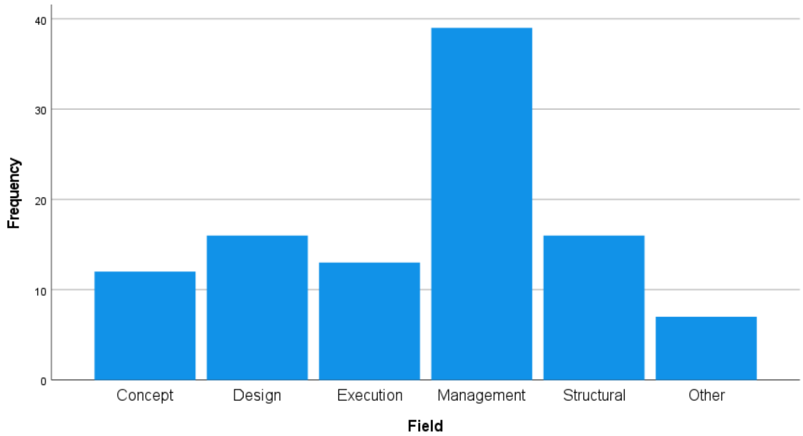

Figure 15:Field of Survey Participants

The majority of the survey takers are within the management department, which was targeted since they are the decision takers when it comes to awarding contracts.

5.1.5 Positions

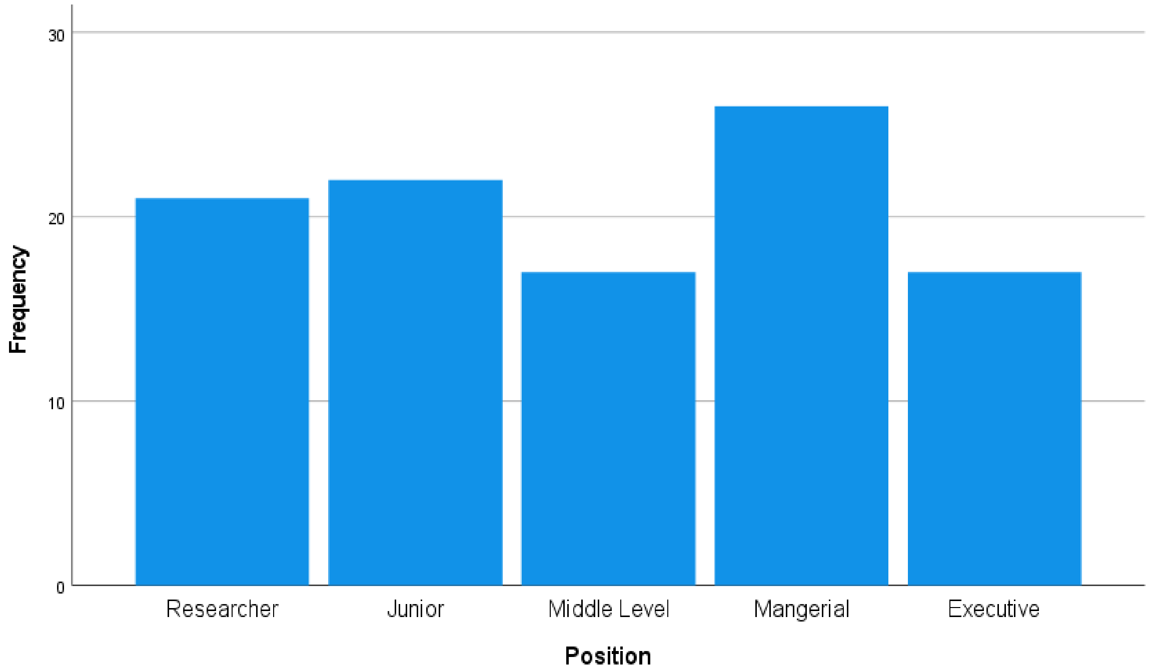

Figure 16:Position of Survey Participants

Even though it would have been very beneficial to get managerial and above survey takers, it was not possible to get all of the sample population within that range, which is why the survey was sent out to different levels.

5.1.6 Years of Experience

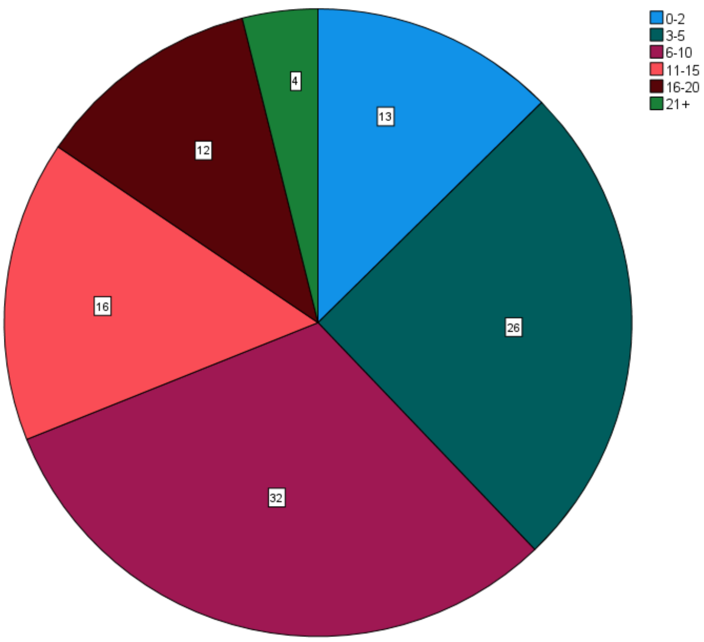

Figure 17: Years of Experience of the Survey Participants

The majority of the survey participants are within the 6-10 years of experience consisting of 31%, and 27% with 11-20 years of experience, which is very beneficial to the survey to ensure rational results.

5.1.7 Correlation Test

The correlation test is used to analyze the degree of relationship between the selected factors and outputs a quantifiable number that can be compared, showing which factors are linearly related and which factors are not. A Pearson's *r* value is computed *where r=+1* is a positive correlation (Directly related), and *r=-1* negative correlation *(inversely related).*

It is also crucial to note that the Significant (2-Tailed) is an important factor that shows when the relationship is by chance or not. When the Significant factor is below 0.05, it shows that there is, in fact, a direct relationship between the factors.

Table 9:Correlations Between Decision Factors

		Cost	Time Frame	Financial Stability	Past Project Performance	Quality rating of previous projects	Completed similar project scale	Safety ratings	References	Availability of staff	Equipment resources	Relevant Experience
Importance of Cost	Pearson Correlation	1	.707**	-.050	.019	-.054	.160	-.205*	.081	-.106	.037	.239*
	Sig. (2-tailed)		<.001	.615	.852	.591	.105	.038	.418	.287	.707	.015
	N	103	103	103	103	103	103	103	103	103	103	103
Importance of Time Frame	Pearson Correlation	.707**	1	.061	-.120	-.100	.074	-.215*	.228*	-.194*	.024	.226*
	Sig. (2-tailed)	<.001		.543	.227	.317	.460	.029	.021	.050	.808	.021
	N	103	103	103	103	103	103	103	103	103	103	103
Importance of Financial Stability	Pearson Correlation	-.050	.061	1	.071	.068	-.211*	-.038	-.016	-.051	-.029	-.030
	Sig. (2-tailed)	.615	.543		.479	.497	.032	.706	.869	.608	.768	.761
	N	103	103	103	103	103	103	103	103	103	103	103
Importance of Past Project Performance	Pearson Correlation	.019	-.120	.071	1	.128	.121	.190	.023	.070	.207*	.274**
	Sig. (2-tailed)	.852	.227	.479		.199	.224	.055	.815	.483	.036	.005
	N	103	103	103	103	103	103	103	103	103	103	103
Importance of Quality rating of previous projects	Pearson Correlation	-.054	-.100	.068	.128	1	-.022	.387**	-.025	.051	-.114	-.043
	Sig. (2-tailed)	.591	.317	.497	.199		.825	<.001	.803	.606	.251	.669
	N	103	103	103	103	103	103	103	103	103	103	103
Importance of Completed similar project scale	Pearson Correlation	.160	.074	-.211*	.121	-.022	1	-.128	.029	-.008	.168	.080
	Sig. (2-tailed)	.105	.460	.032	.224	.825		.199	.772	.935	.090	.421

	N	103	103	103	103	103	103	103	103	103	103	103
Importance of Safety ratings	Pearson Correlation	-.205*	-.215*	-.038	.190	.387**	-.128	1	-.067	.097	-.009	.063
	Sig. (2-tailed)	.038	.029	.706	.055	<.001	.199		.502	.328	.929	.528
	N	103	103	103	103	103	103	103	103	103	103	103
Importance of References	Pearson Correlation	.081	.228*	-.016	.023	-.025	.029	-.067	1	-.029	.066	.189
	Sig. (2-tailed)	.418	.021	.869	.815	.803	.772	.502		.770	.508	.056
	N	103	103	103	103	103	103	103	103	103	103	103
Importance of Availability of staff for the project	Pearson Correlation	-.106	-.194*	-.051	.070	.051	-.008	.097	-.029	1	-.004	.072
	Sig. (2-tailed)	.287	.050	.608	.483	.606	.935	.328	.770		.965	.467
	N	103	103	103	103	103	103	103	103	103	103	103
Importance of Equipment resources	Pearson Correlation	.037	.024	-.029	.207*	-.114	.168	-.009	.066	-.004	1	-.006
	Sig. (2-tailed)	.707	.808	.768	.036	.251	.090	.929	.508	.965		.955
	N	103	103	103	103	103	103	103	103	103	103	103
Importance of Relevant Experience	Pearson Correlation	.239*	.226*	-.030	.274**	-.043	.080	.063	.189	.072	-.006	1
	Sig. (2-tailed)	.015	.021	.761	.005	.669	.421	.528	.056	.467	.955	
	N	103	103	103	103	103	103	103	103	103	103	103
**. Correlation is significant at the 0.01 level (2-tailed).												
*. Correlation is significant at the 0.05 level (2-tailed).												

The value of 1 given as a Pearson's coefficient is only given to factors that are being compared with themselves. However, multiple values shown in Table 8 have direct relationships with each other such as Cost and Time, with a Pearson's coefficient of 0.707 and a significant factor of less than 0.001. These relationships will help in understanding the decision factors and how experts assess the importance of each one with respect to the project.

It is also important that multiple survey takers pointed out that the importance of the factors depends on the type of the project and requirements. It was explained to them that this is just for the research purpose since the framework's aim will take into account the project's requirements prior to initiating the process. Each client will have to state what is important for the project in their expert opinion, and it will be taken into account to recalibrate the calculations done by the code.

5.2 Decision Factors Discussion

There are a few methods that are usually used in awarding a contractor such as: lowest bid, best value (Low price, highest qualifications), and most qualified (Cost takes a lower weight when it comes to decision making).

Depending on the company that is awarding the contract, the weights of the decision factors will differ, which is why the survey came back with different opinions about the decision factors.

5.2.1 Cost

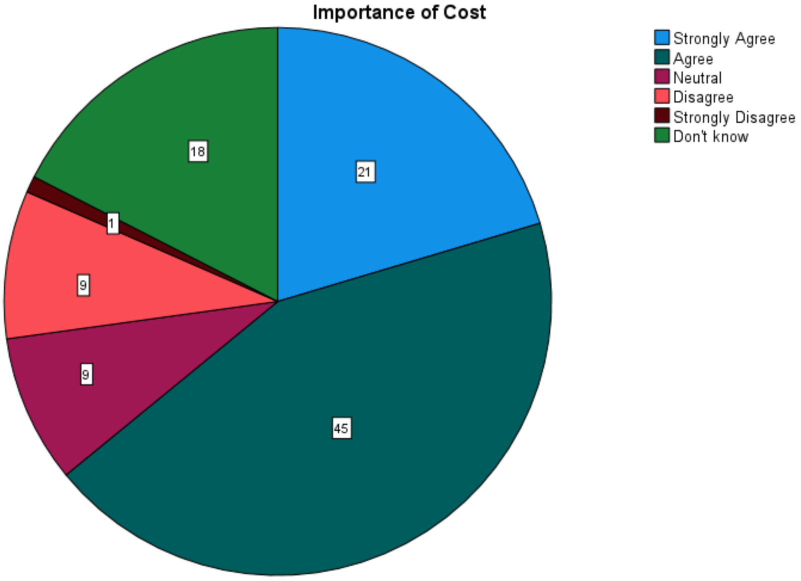

Figure 18: Survey responses about Cost Importance

It was foreseeable for the majority of the survey participants to agree that the cost is one of the most important factors when it comes to selecting a contractor. However, it can also be seen in Figure 19 that not everyone believes that the cost is the most important factor when it comes to selecting the contractor; some might believe that the quality that the contractor provides is more important.

5.2.2 Duration

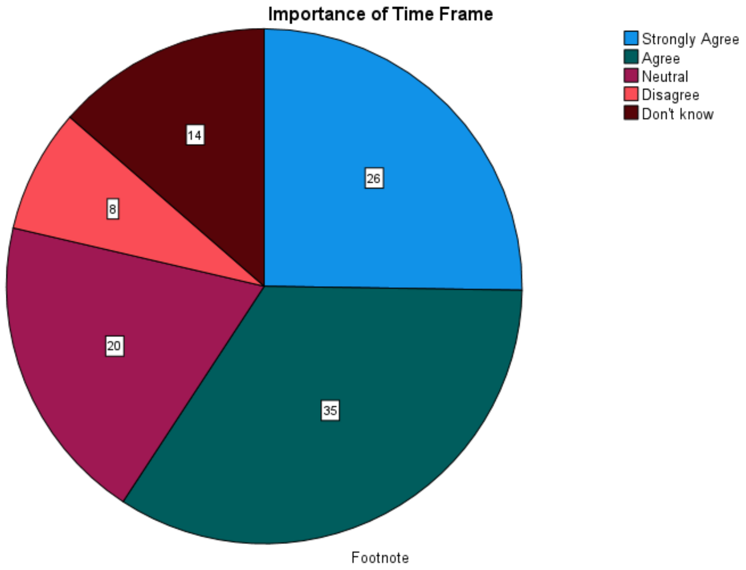

Figure 19:Survey responses about Duration Importance

As construction projects are typically dependent on a timeline with a deadline that needs to be achieved, the majority of the survey participants have agreed that it is, in fact, one of the important factors that need to be taken into account (the shortest time frame of the project). The timeline is important since each day that passes after the deadline, and the client would be losing money which is why there is usually a penalty that is applied to a contractor if the project is delayed. However, the reputation of the client is also at risk that the company's projects are "typically delayed," which is very important to maintain as a developer.

5.2.3 Financial Stability

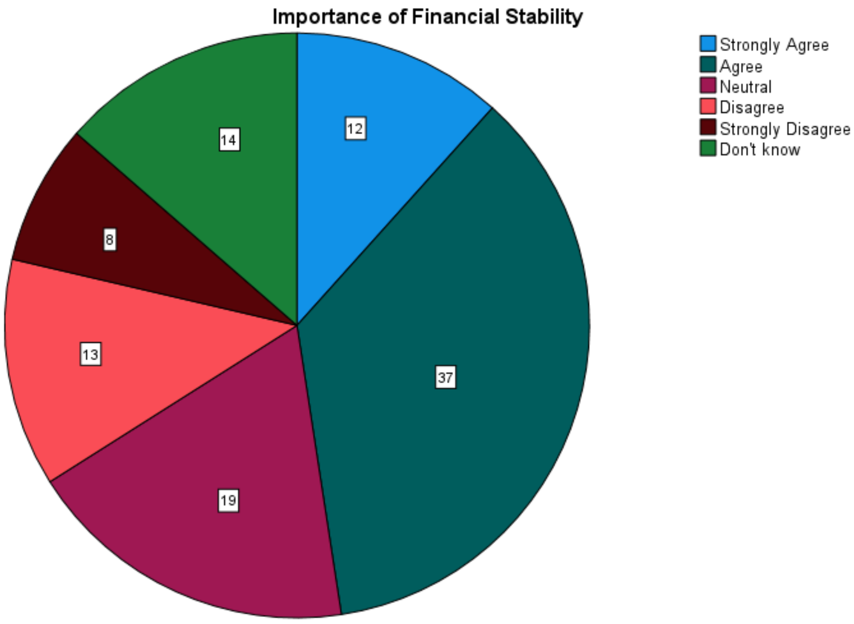

Figure 20:Survey responses about Financial Stability Importance

Even though a new project means new cash flow to the company, however, many projects fail to meet the project's success criteria (delayed or poor quality, etc.) due to poor financial situation. The main reason is that the contractor would be delaying payments to subcontractors, routing the money of the project to support another project and so on. This poor finances can lead to project failure, which is why the majority also agree that the financial situation of a contractor is an important factor that needs to be taken into account as shown in Figure 21.

5.2.4 Past Project Performance

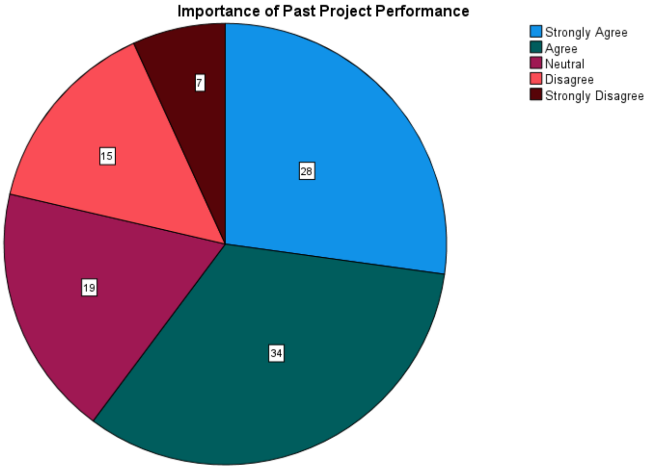

Figure 21:Survey responses about Previous Performance Importance

Most consultants and clients view multiple projects of the contractor prior to awarding the contract to check out the progress, quality, and issues that were faced and are facing in completed and ongoing projects. This allows them to see the contractor's performance and their capabilities to ensure that they are able to complete the project within the required quality. The survey participants 62 participants out of the 103 agree that it is an important decision factor to ensure a successful project.

5.2.5 Quality Ratings of Previous Projects

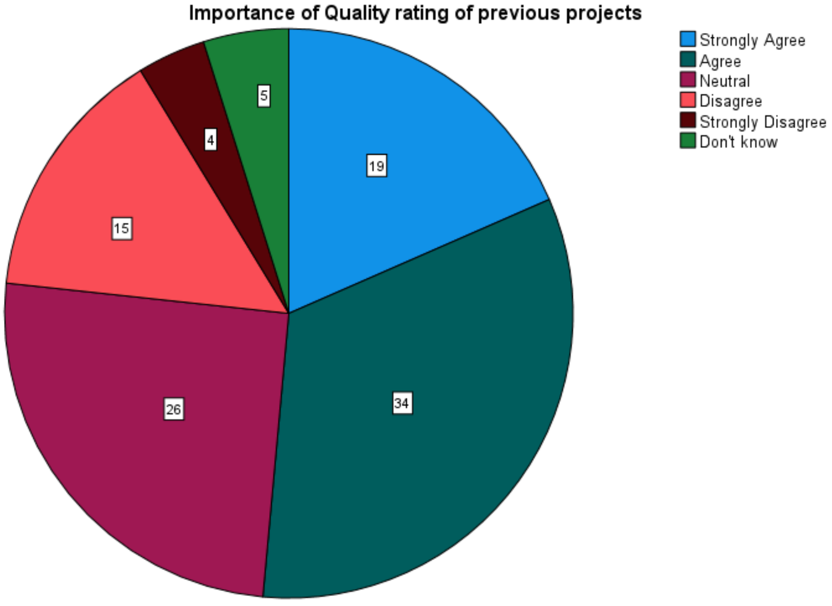

Figure 22: Survey responses about Quality Importance

As the quality is one of the pillars in every project alongside the cost and time, as shown in Figure 23 most of the participants agree that it needs to be weighted highly on the scale of importance when it comes to decision factors.

5.2.6 Completed Similar Projects with the same scale

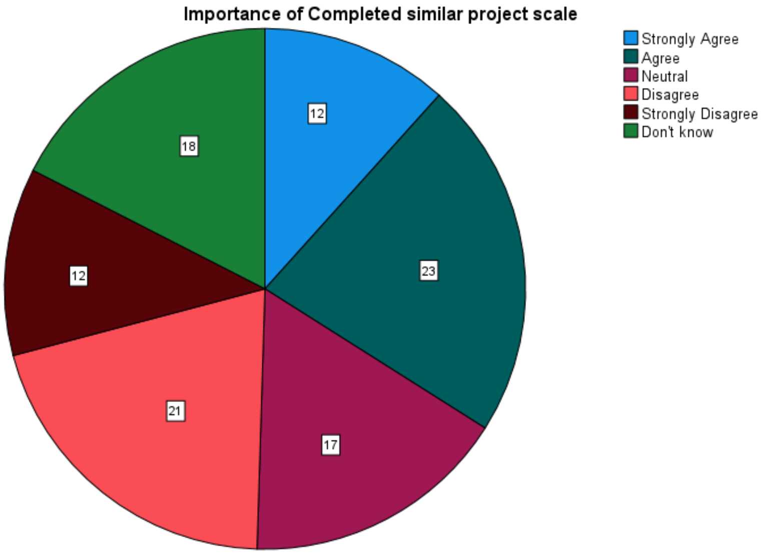

Figure 23: Survey responses about Previous Similar Scale Project Importance

Different opinions resulted from the survey regarding the requirement of a contractor to have complete projects with the same scale as the project that will be awarded. This means that the survey participants believe that a company that works on small scale projects can in fact work in a big scale project if given the right opportunity.

5.2.7 Safety Ratings

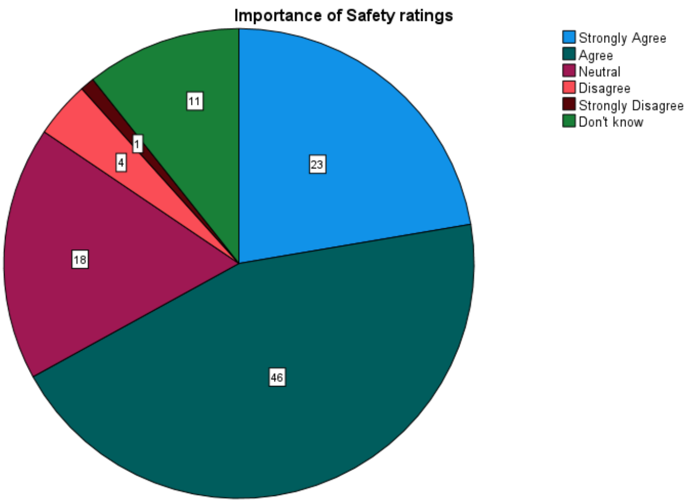

Figure 24: Survey responses about Survey Importance

The safety decision factor was in fact the most unanimous rating with the majority agreeing about the importance of it when it comes to awarding projects. Other than the obvious importance of human life, when it comes to projects, even small incidents can put the entire project on hold until to ensure that it will not happen again. Only a select few disagree and that might be due to the fact that safety awareness can be implemented and enforced.

5.2.8 References from Previous Projects

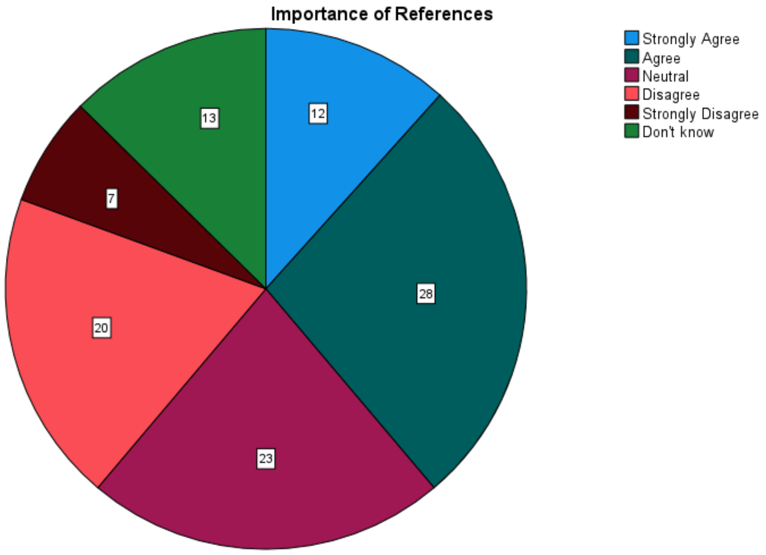

Figure 25: Survey responses about References Importance

The survey majority of the survey participants agree that it is a good factor that the contractors have references that can be contacted since the credibility and progress can be confirmed by a third party; however, the difference is not huge as only 40 people agree that it is important. However, even though a contractor might have completed the project successfully arguments and disagreements might lead to breaking the relationships and removing a previous client as a reference even though the project was successful which is why some survey takers did not agree.

5.2.9 Availability of Staff for the Project

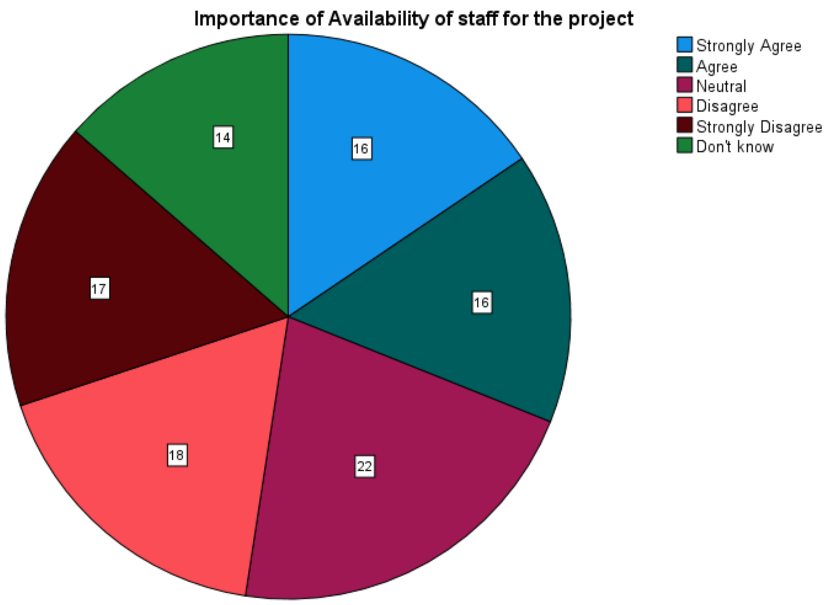

Figure 26: Survey responses about Staff Availability Importance

Having available staff for a project depends on the company's policy as some companies are project based (they hire based on the available projects, and terminate accordingly) and other companies have a core team and add as necessary. Which is why the response from the survey participants is divided which concludes that it is not necessary for a company to have the staff available since they can always hire if the project was awarded to them.

5.2.10 Equipment Resources

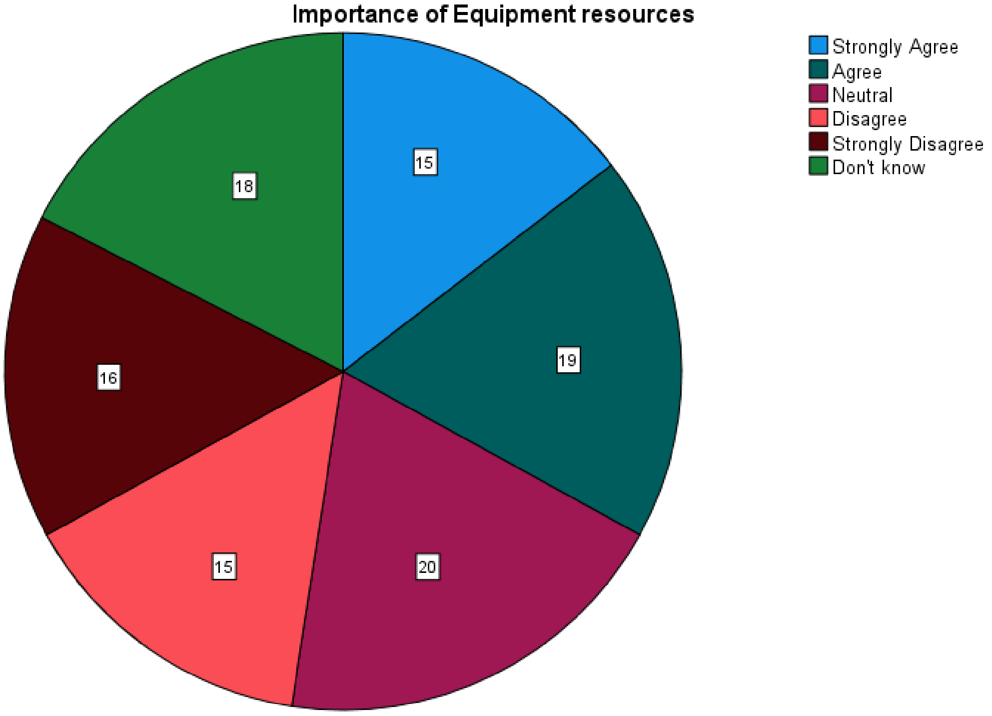

Figure 27: Survey responses about Machinery Resources Importance

Having sufficient equipment and machinery for a project depends on the company's policy as some companies rent out their machinery for the duration of a project, and others buy/sell them based on the projects at hand. Which is why the response from the survey participants is divided which concludes that it is not necessary for a company to have the required machinery on standby since they can always rent or buy them if the project was awarded to them.

5.2.11 Relevant Experience

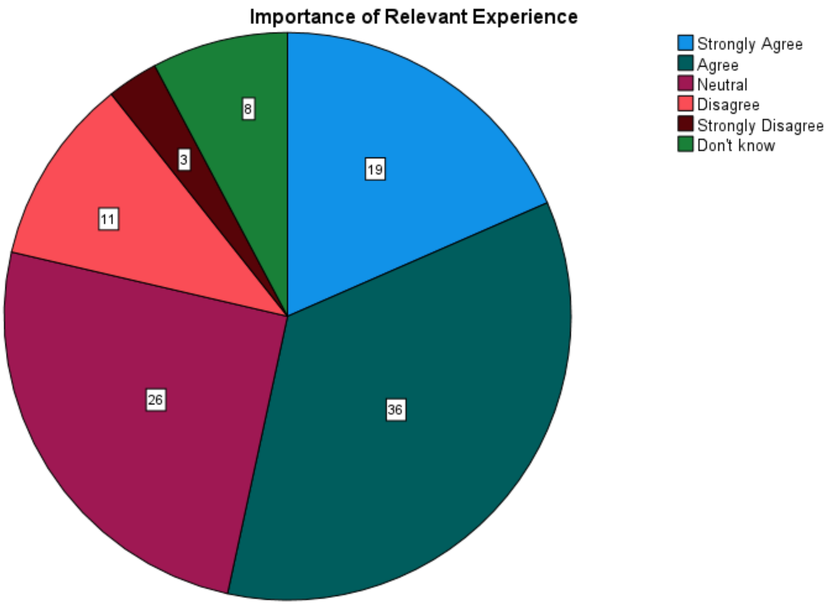

Figure 28: Survey responses about Relevant Experience Importance

The majority of the survey participants agreed that it is important to have relevant experience when it comes to the project type (such as infrastructure projects background, high-rise towers, villas, etc.). Even though the scale of projects was not found to be an important factor to the survey participants, the type of project and experience are deemed important as the staff will have previous experience and knowledge about the difficulties that can be faced in a similar project even though the scale is different (what can happen in one villa might happen in a 100). Which is why having relevant experience has been found to be an important decision factor.

As can be shown from the above figures the most important decision factors that were found can be shown in Table 9 sorted from the highest to the lowest agreement rate.

Table 10: Decision Factors Agree frequencies

ID #	Decision Factors	Number of Participants who Agree & Strongly Agree	Percentage out of all the survey participants
1	Safety	69	67%
2	Cost	66	64%
3	Past performance	62	60%
4	Time frame	61	59%
5	Relevant Experience	55	53%
6	Past Quality	53	51%
7	Financial Stability	49	48%
8	References	40	39%
9	Similar Scale	35	34%
10	Equipment resources	34	33%
11	Availability of Staff	32	31%

The weights of these factors will depend on the percentage of "agree" and "Strongly Agree" frequencies which is why the top four decision factors were taken which are Safety, Cost, Past performance, and Time frame, and weighted higher than the others. The eleven decision factors' weight needs to be out of one, which is why the first decision factors' combined weight became as shown in Table 10.

Table 11: Weight of Decision Factors

Decision Factors	Weight of Decision Factors
Safety	0.15
Cost	0.15
Past performance	0.115
Time	0.115
Relevant Experience	0.1
Quality	0.1
Financial Stability	0.07
References	0.05

Similar Scale	0.05
Equipment resources	0.05
Availability of Staff	0.05

These weights will be used to measure the “success rate” of the projects in the tendering phase using a Multiple Linear Regression model in Google Colab. Using a dataset that was found in Data World, which includes governmental datasets that are trusted. The Success rate for the project that is ongoing had to be manually calculated since no previous data was provided about the contractors. However, with time the data set will be built (after the results of each project are updated once it is completed), which will allow the model to predict future success rates during the tendering phase of other projects. The model was built on a machine learning algorithm using Google Colab with the python language. The MLR models the linear relationships of the dependent variable (in this case, it is the “Success rate,” which was manually computed using the number of the survey weights) and the independent variables which are the decision factors that were found during the literature review. The model that was created was divided into the following steps:

1) Clean the Dataset obtained:
   - The dataset included numerous data that are irrelevant such as the codes of the project, city within the states, and project discerption which had to be removed.
   - Projects with Blank data, had to be also removed.
   - Durations had to be computed from the Projects Start and End dates.
   - Formatting the data to a Comma separated line file.

A sample of the long dataset can be shown in Appendix B, where two tables are attached that show the cleaned data as a table separating the different categories by columns and the comma-separated line table which shows the continuous line data which can be used in Google Colab.

2) Import the required data analysis Application Programming Interface (API), which will be used, including “Pandas”. The API will obtain the data, retrieve the function which will be applied, and output the results depending on the perimeters of the function and configuration of the dataset.

```
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
```

Figure 29: Importing the Required APIs

3) Upload the cleaned dataset into google colab.
4) Split the data into two axis X and Y to be able to predict the success rate.
5) Within the X axis the column that will be predicted needs to be dropped from the dataset (so it can be configured) which is the manually computed “Success Rate”.
6) Whereas, in the Y axis, the Success rate column will be introduced as the primary aim of the regression analysis which will be conducted.
7) The X and Y axis split will allow a comparison at the end so that the model can compute the accuracy percentage.

8) The decision factors then need to be identified within the list so that the model can start learning to use the data from each project by going through the decision factors in order to compute the success rate.
9) Use one hot encoding on the identified decision factors to translate them into binary codes for each decision factor to enable the model to analyze the data. This is used for any category that the data is in non-binary format.

```
from sklearn.preprocessing import OneHotEncoder
from sklearn.compose import ColumnTransformer

categorical_feature = ['Borough', 'Managing_Agency', 'Category']
one_hot = OneHotEncoder()
transformer = ColumnTransformer([("one_hot",
                                  one_hot,
                                  categorical_feature)],
                                 remainder="passthrough")

transformed_X = transformer.fit_transform(X)
transformed_X
```

Figure 30: Importing One Hot Encoder Function

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1234	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
1235	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
1236	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
1237	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
1238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0

1239 rows × 38 columns

Figure 31: Results of the One-Hot Encoder

10) Split the data into a Training Set and a Testing Set (70-30 split), which uses 70 percent of the data to train the model to compute the success rate, and 30 percent to test if the model works properly. This is used to avoid "Overfitting"; Overfitting the model leads to good outputs of this dataset, however, it will result in poor results if new data is introduced.
11) Training the Multiple Linear Regression Model using the training set (which was dictated in the previous step).
12) Obtain the regressor score and analyze it. The regressor score means that if a similar dataset is uploaded to this model, the model is able to analyze the accuracy of it up to

this score; which in the case of the model used was 0.98 (or 98%). This does not mean that it is accurate up to 98% since datasets will vary the regressor score will drop.

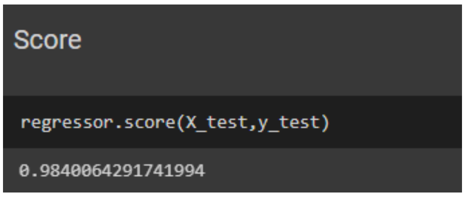

Figure 32: Regressor Score

To ensure high accuracy, the datasets that have been used need to expand and new datasets to be entered, which will happen with time as new project data is used and configured accordingly since the model uses machine learning.

The model aims to predict the success rate of a project when going with a specific contractor that has been rated in previous projects. So if contractor A has completed projects previously and the consultant/client has rated his performance in terms of that specific project, it will be added to the dataset so that if a new project comes up and Contractor A wants to Bid on the project, this model can see how successful he will be based on the previous performance. The model can also be altered as required to add the type of project as initially discussed to separate contractor experiences into different categories instead of having a number for ease of use and computation, a category can be added, and depending on the preferences of the consultant/ client the weights of each decision factor can be inputted to see how well the Contractor fits for the project at hand.
This research aims to improve the tendering process in the construction industry; however, it can be applied in different industries by selecting the right decision factors based on the tendering requirements. Process modeling is one of the rising improvements in the tendering process, which aims to improve communication between different parties, increase transparency, and improve the quality of the decisions being made (Noor & Papamichail, 2013). Improving the quality of decisions is great, but the process still takes plenty of time and resources, costing money to all parties involved. The model created in this research drastically decreases the costs associated with the tendering process and assures that the contractors selected can complete the project. Eliminating contractors that are not capable of completing the project or are not the best options (they have a low percentage of being awarded the contract) will save them the time and money associated with tendering and, at the same time, save the client and consultant the trouble of analyzing and evaluating it which requires time from their resources which can be put to better usage.
As public contracts should typically be awarded to the best company that can complete the project, numerous countries do not have a validated system to ensure that, which increases corruption in some countries as people in power award the contracts to people that benefit them (Amayi & Ngugi, 2013). Moreover, immense amounts of money are lost due to corruption and bribery, estimated at billions of dollars yearly (Zouaoui, Al Qudah, & Ben-Arab, 2017). The model that has been created in this research is one way that can ensure governmental projects are awarded based purely on the best contractor (as per their requirements) and ensure fairness and transparency by all parties, which will decrease the

corruption within the country and not only in the construction industry but different industries if appropriately used.
However, the model still needs a long way to go to ensure high accuracy and fairness in the results, which can be achieved by having companies put in a small amount of work. As the model works on the data being provided, it is essential to supply the model with accurate data to achieve accurate results and, of course, valid data (not manipulated data). This part of the model depends on humans, which comes with the risk of human errors and human corruption. A simple example could be that the person in charge of using the model leaks the requirements, and the contractor will adjust their qualifications based on it to achieve the highest score. This is the prime reason that, as a recommendation for the project, a third party needs to oversee the uploaded data and authorize them after checking if they are valid. Another limitation to the model, which is common in most Artificial intelligence frameworks, is the validation of the results as the model has been created based on the survey results (decision factors selection) and the used data; which needs to be used in numerous different contracts to ensure the accuracy and workability of the model (Bolpagni, 2018).

Figure 34 explains how the different parties interact with the framework in the design phase prior to the beginning of the project, and Figure 35 shows how the dataset can be regularly updated to ensure up-to-date data for other projects. Each project can alter the decision factors as they see fit and access the latest data to award new contracts.

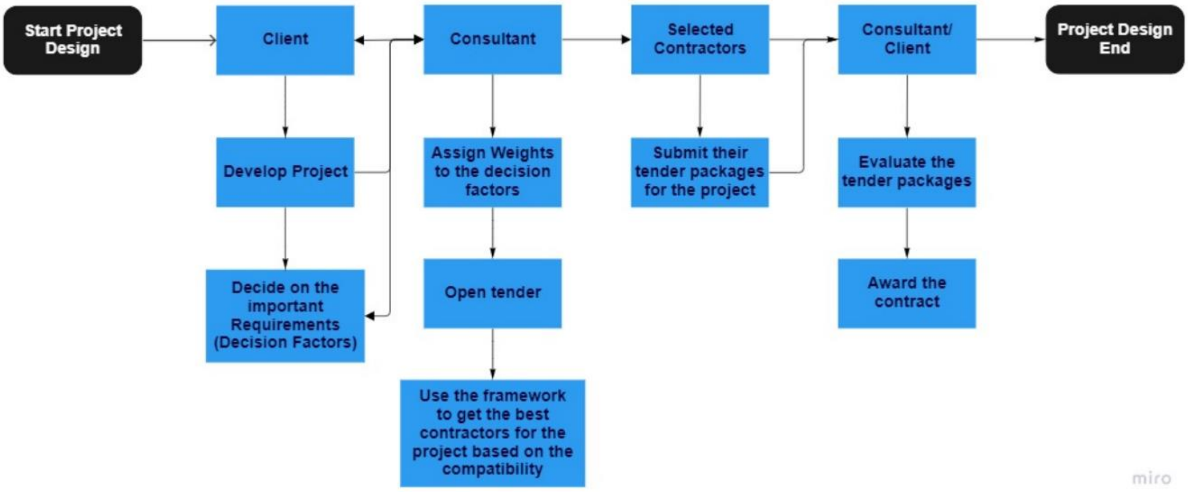

Figure 33:Framework Flowchart

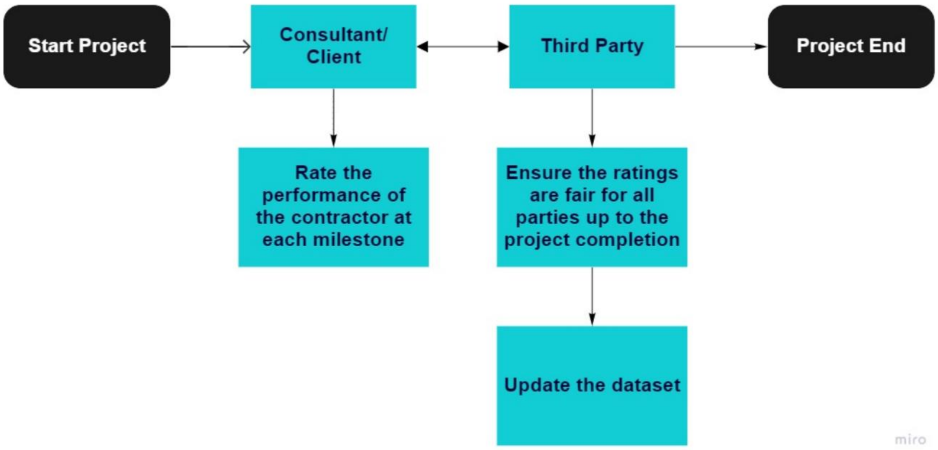

Figure 34: Updating the Dataset Flowchart

CHAPTER SIX – CONCLUSION

6.1 Conclusion and recommendations

To conclude, the model that has been created is a part of a framework that can increase the number of applicants for a single contract and hand pick the best "X" number of contractors (depends on how many the consultant/client wants to tender) by predicting the success rate of the project based on the decision factors of the project for each contractor that is included in the dataset. The framework will save contractors vast amounts of money and time on tendering for projects that they are not fit for and do not have a chance to get, and at the same time, ensure the consultant/client a higher success rate of project completion with the contractors who have the highest success rate while decreasing efforts and time by going through numerous tender packages. Shifting from the traditional tendering process, which requires a long period of time, and costs plenty of money, to the framework will ensure higher revenues for all parties and save them valuable time while ensuring a higher project success rate. The objective of this research was to thoroughly examine the existing tendering process, determine how a new framework will improve the traditional tendering process, and finally create the framework; the framework was created including a set of steps to determine the decision factors which will be incorporated in the model created to ease the tendering process significantly and generate accurate results. However, this framework is still a work in progress and needs to be improved using more extensive datasets and live ones (regularly updated) to increase the overall accuracy of the framework; as the data uploaded to the dataset increases, the model will yield more accurate results. Nevertheless, this research is a starting point that will be built on and enhanced by other research projects to reach a new tendering process that is more beneficial to all parties. To implement this framework with total efficiency, all parties involved need to put in a small effort by submitting their projects' information, and consultants to submit the project's ranking based on actual non-biased expert's opinions so that the database that will be used in future projects can stay up to date and accurate since this database will be the base of the model. Decision factors can be altered, and their weights can be changed depending on each consultant/client's requirements. However, if the parties involved do not update the database, the model will fail or become outdated, yielding inaccurate success rates and end up harming the projects it is used in. The recommendation for the future progress of the framework would be to have a governmental system put in place where projects are regularly updated at different stages of each project so that when a new contract is going to be awarded, the dataset would be up to date, and it can also be regulated by a third party that oversees any concerns when it comes to poor or outstanding ratings to ensure fairness in the dataset and no biased ratings. This framework can also help in governmental contracts since the governmental contracts need to be spread based on an open tender system to ensure openness and fairness to all contractors, so depending on a project, the "Best" company for the type of project can be awarded the contract between all of the companies that are within the database.

REFERENCES

Aapaoja, A., Kinnunen, T., & Haapasalo, H. (2013). Stakeholder Salience Assessment for Construction Project Initiation. *International Journal of Performance Measurement*.

Abdul Rahman, I., & Mermon, A. (2013). The Way Forward in Sustainable Construction: Issues and Challenges. *International Journal of Advances in Applied Sciences*.

Adeleye, A. (2016). Relevance of Contractors' Prequalification Criteria to Time Performance of Civil Engineering Project. *American Journal of Civil Engineering*, 225-232.

Aigbavboa, C., & Thwala, W. (2020). The Construction Industry in the Fourth Industrial Revolution. *Proceedings of 11th Construction Industry Development Board (CIDB) Postgraduate Research Conference*.

Akcay , C., & Manisali, E. (2017). Fuzzy decision support model for the selection of contractor in construction works. DOI: 10.7764/RDLC.17.2.258.

Akkerman, S. (2016). A Multi-criteria decision support system for optimal allocation of subcontractors in construction projects.

Alamoudi, R., & Balubaid, M. (2015). Application of the Analytical Hierarchy Process (AHP) to Multi-Criteria Analysis for Contractor Selection. *American Journal of Industrial and Business Management*, *5*, 581-589.

Amalia , C., & Setyohadi, D. B. (2018). Selection Contractors in E-Tendering Procurement of Goods and Services Bureau Central Kalimantan Using Analysis Network Process. *EDP Sciences* .

Amayi, F. K., & Ngugi, D. K. (2013). Determinants of Public Procurement Performance in Kenya: case Ministry of Environment,Waterand Natural Resources. *International Journal of Human Resource and Procurement*, 647-667.

Anagnostopoulos, K., & Vavatsikos, A. (2006). An AHP Model for Construction Contractor Prequalification. *Operational Research. An International Journal*, *6*(3), 333-346.

Authority, P. P. (2009). Procurement Reforms in Kenya. *Journal of Purchasing*.

Babič, N., Podbreznik, P., & Rebolj, D. (2010). Integrating resource production and construction using BIM. *Automation in Construction*, 539-543.

Belekar, S., Jamadar, S., Singh , R., Manjarekar, J., & Kazi, A. (2021). Application of Analytical Hierarchy Process (AHP) in Construction Works. *International Journal of Engineering Research & Technology (IJERT)*, *9*(3), 134-137.

Bilgin, A. (2007). Key Differences Between Turkish Procurement Legislation and Directive 2004/18/EC. *$th Construction Management Congress.* Istanbul: Official Journal of the European Union.

BOLPAGNI, M. (2018). Digitalization of tendering and awarding processes: a building information modeling (BIM) - based approach to public procurement routes.

Cakmak, E., & Cakmak, P. I. (2014). An Analysis of Causes of Disputes in the Construction Industry Using Analytical Network Process. *Procedia - Social and Behavioral Sciences*, 183-187.

Chan, L., Chiu, D., & Hung, P. (2007). e-Tendering with Web Services: A Case Study on the Tendering Process of Building Construction. *IEEE International Conference on Services Computing (SCC 2007),* 582-588.

Clack, C. D., Bakshi, V. A., & Braine, L. (2017). Smart Contract Templates: foundations, design landscape and research directions.

Darko, A., Chuen Chan, A., Ameyaw, E., Owusu, E., Parn, E., & Edwards, D. (2019). Review of application of analytic hierarchy process (AHP) in construction. *International Journal of Construction Management* , 436-452.

Doskočil, R. (2015). An Evaluation Of Total Project Risk Based On Fuzzy Logic. *Business: Theory and Practice*, 23-31.

El Agroudy , M., Elbeltagi, E., & El Razek, M. E. (2009). A Fuzzy Logic Approach for Contractor Selection. *Fifth International Conference on Construction in the 21st Century* . Istanbul: ACADEMIA.

El-Sayegh, S., Irtishad, A., Aljanabi, M., Herzallah, R., Metry, S., & El-Ashwal, O. (2020). Construction Disputes in the UAE: Causes and Resolution Methods. *Buildings 10*, 171.

Eshtehardian, E., Ghodousi, P., & Bejan, A. (2013). Using ANP and AHP for the supplier selection in the construction and civil engineering companies; Case study of Iranian company. *KSCE Journal of Civil Engineering*, 262–270.

Falamarzi , M. H. (2020). *Application of Multi Criteria Decision Making in Tender Evaluation: A Study Using ANP Model.* Qatar University .

Fong, P. S.-W., & Choi, S. K.-Y. (2000). Final contractor selection using the analytical hierarchy process. *Construction Management and Economics, 18*(5), 547-557, DOI: 10.1080/014461900407356.

Fullbright, N. R. (2016). Smart Contracts: Coding the Fine Print. *A Legal and Regulatory Guide*.

Harty , C., Goodier, C. I., Soetanto, R., Simon, A., Dainty, A., & Price, A. (2006-2007). *The futures of construction: a critical review of construction future studies.* Construction Management and Economics.

Hatush, Z., & Skitmore, M. (1998). Contractor Selection Using Multicriteria Utility Theory: An Additive Model. *Building and Environment*, 105-115.

HMG. (2015). Digital Built Britain: Level 3 Building Information Modelling—Strategic Plan. *London: HM Government*.

Holt, C., Edwards, L., Keyte, L., & Moghaddam, F. (2019). 3D Concrete Printing Technology. 349-370.

Holt, G. (2010). Contractor selection innovation: examination of two decades' published research. *Construction Innovation Emerald Group Publishing Limited*, 304-328.

Hoseinpoor, A., & Alborzi, M. (2019). The Combination of DEA and AHP Approach in the Selection of Contractors Paticipating in Tenders. *HOLOS, 2*.

Hsieh, T.-Y., Lu, S.-T., & Tzeng, G.-H. (2004). Fuzzy MCDM approach for planning and design tenders selection in public office buildings. *International Journal of Project Management*, 573-584.

International, T. (2015). *Corruption Perceptions Index 2014.*

Jafari , A. (2013). A contractor pre-qualification model based on the quality function deployment method. *Construction Management and Economics, 31*(7), 746-760, DOI: 10.1080/01446193.2013.825045.

Jin, H., Zhang, M., & Yuan, Y. (2018). Analytic Network Process-Based Multi-Criteria Decision Approach and Sensitivity Analysis for Temporary Facility Layout Planning in Construction Projects. *Appl. Sci.*

Kalanaki, A. (2013). *Tender Evaluation for the Telecommunication Industry using the Analytic Network Process.* The Research Repository of West Virginia University .

KELLEY, K., CLARK, B., BROWN, V., & S., J. (2003). Good practice in the conduct and reporting of survey research. *International Journal for Quality in Health Care*, 261-266.

Khairuddin, S. H., Hasan, M. H., Hashmani, M. A., & Azam, M. H. (2021). Generating Clustering-Based Interval Fuzzy Type-2 Triangular and Trapezoidal Membership Functions: A Structured Literature Review. 239.

Khosrowshahi,, F. (1999). Neural network model for contractors' prequalification for local. *Engineering, Construction and Architectural Management*, 315-328.

Kumaraswamy, M. M. (1996). Contractor evaluation and selection: a Hong Kong perspective. *Building and Environment*, 273-282.

Lai, K. K., Liu, S. L., & Wang, S. Y. (2004). A method used for evaluating bids in the Chinese Construction industry. *The International Journal of Project Management*, 193-201.

Li, X., & Wang, X. (2022). The application of an ANP-Fuzzy comprehensive evaluation model to assess lean construction management performance. *Engineering, Construction and Architectural Management*.

Lapidus, A., & Makarov, A. (2016). Fuzzy sets on step of planning of experiment for organization and management of construction processes. *MATEC Web Conf.*

Laryea , S. (2010). Quality of tender documents: case studies from the UK. *Construction Management and Economics*, 275-286.

Legay, A., Delahaye, B., & Bensalem , S. (2010). Statistical Model Checking: An Overview. *International Conference on Runtime Verification*, 122–135.

Lenderink, B., Halman, J., & Boes, H. (2022). A method to encourage and assess innovations in public tenders for infrastructure and construction projects. *Emerald Insight*.

Lesnaik, A., Kubek, D., Plebankiewicz, E., Zima, K., & Belniak, S. (2018). Fuzzy AHP Application for Supporting Contractors' Bidding Decision . *Symmetry*.

Lin, C. C., Wang, W.-C., & Yu, W.-D. (2008). Improving AHP for construction with an adaptive AHP approach. *Automation in Construction*, 180-187.

Mahdi, M., Heiza, K., & ElSheikh, M. (2018). Contractor Capabilities Evaluation Model From Risk Perspective Using Analytic Network Process. *Engineering Research Journal, 41*(1), 22-35.

Makwana, A. (2013). An Approach for Ready Mixed Concrete Selection for Construction Companies through Analytic Hierarchy Process. *International Journal of Engineering Trends and Technology (IJETT).*

Marovic, I., Peric, M., & Hanak, T. (2021). A Multi-Crteria Decision Support Concept for Selecting the Optimal Contractor. *Applied Sciences, 11*, https://doi.org/10.3390/app11041660.

Mohamed, S. R., & Majeed, R. A. (2016). Using Analytical Network Process to Find Priorities Weights of Contractors Pre-Qualification. *Journal of Construction Engineering, Technology and Management, 6*(2), 88-93.

Mohemad, R., Razak, A., & Zulaiha Ali, H. (2014). Decision Support Systems (DSS) in Construction Tendering Processes. *IJCSI*.

Noor, M., & Papamichail. (2013). *Process modelling for online communications in tendering processes.*

Ofori2, G. (2015). Nature of the Construction Industry, Its Needs and Its Development: A Review of Four Decades of Research. *Journal of Construction in Developing Countries*, 115-135.

Phillips, S., Dainty, A., & Price, A. (2007). The development of a tender analysis support tool for use in social housing best value procurement. *Proceedings of the 23rd Annual ARCOM Conference* (pp. 797-808). Belfast: The Association of Researchers in Construction Management.

Qiao, Y., & Cummings, G. (2003). The Use of Qualifications-Based Selection in Public Procurement: A Survey Research. *Journal of Public Procurement, 3*(2), pp.215-249, https://doi.org/10.1108/JOPP-03-02-2003-B004.

Qualifications Based Selection of Contractors . (2009). *The Associated General Contractors of America* .

Ritz, G. J. (1994). *Total construction project management.* New York: McGraw-Hill.

Rosmayati, M., HAMDAN, A. R., Zulaiha, A. O., & Maizura, N. (2010). Decision Support Systems (DSS) in Construction Tendering Processes. *IJCSI International Journal of Computer Science Issues*.

Russell, J. S., & Skibniewski, M. J. (1990). QUALIFIER-1: CONTRACTOR PREQUALIFICATION MODEL. *Journal of Computing in Civil Engineering*.

Sadeghi-Niaraki , A., Kim, K., & Varshosaz, M. (2010). Multi-Criteria Decision-based Model for Road Network Process. *International Journal of Enviornmental Research*, 573-582.

Sepasgozar, S., Davis, S., Loosemore, M., & Bernold, L. (2018). *An investigation of modern building equipment technology adoption in the Australian construction industry.* Engineering, Construction and Architectural Management.

Smith, A. J. (1995). *Estimating, Tendering and Bidding for Construction.* Hong Kong.

Su, L., Wang, T., Li, H., Cao, Y., & Wang, L. (2020). Multi-Criteria Decision Making for Identification of Unbalanced Bidding. *Journal of Civil Engineering and Management, 26*(1).

Stephen, K., & Achim, W. (2004). E-Tendering: Benefits, Challenges and Recommendations for Practice. *Construction Innovation International Conference Proceedings*, 1-11.

Thomas, S., Cheung, S., Skitmore, M., & Wong, T. (2002). An integrated regression analysis and time series model for construction tender price index forecasting. *Construction Management and Economics* , 483-493.

Vidregor, D. E. (2016). The Multidimensional Curriculum Model (MdCM). *Gifted and Talented International* , 153-165.

Wang, W.-C., Yu, W.-d., Yang, I.-T., Lin, C.-C., Lee, M.-T., & Cheng, Y.-Y. (2013). Applying the AHP to Support the Best-Value Contractor Selection-Lessons Learned from Two Case Studies in Taiwan. *Journal fo Civil Engineering and Management, 19*(1), 24-36, doi:10.3846/13923730.2012.734851.

Wong, C. H., Holt, G. D., & Cooper, P. A. (2010). Lowest price or value? Investigation of UK construction clients' tender selection process.

WONG, C., HOLT, G., & HARRIS, P. (2001). Multi-criteria selection or lowest price? Investigation of UK construction clients' tender evaluation preferences. *Engineering, Construction and Architectural Management*.

Wu, H., & Xu, Z. S. (2021). Fuzzy Logic in Decision Support: Methods, Applications and Future Trends. *International Journal of Computers Communications & Control, 16*(1).

Zadeh, L. (1965). Fuzzy sets as a basis for a theory of possibility. *Fuzzy Sets and Systems*, 3-28.

Zare, S., Shirvan, H. E., Hemmatjo, R., Faridan, M., Hajghani, M., & Dehaghi, B. F. (2018). Using the Analytic Network Process Method for Prioritizing and Weighting Shift Work Disorders Among the Personnel of Hospitals of Kerman University of Medical Sciences. *Journal of Circadian Rhythms, 16*(10), doi: 10.5334/jcr.163.

Zebardast, E. (2010). The Application of Analytic Network Process (ANP) in Urban and Regional Planning. 79-90.

Zouaoui, A., Al Qudah, A., & Ben-Arab, M. (2017). World Corruption Perception Index Analysis. *Research Journal of Finance and Accounting*.

APPENDIX A

Framework to shortlist contractors in the tendering phase						
Demographics						
Please answer the following Questions or leave the question blank if you do not which to disclose the information						
Gender	Male			Female		
Age	18-20	21-30	31-40	41-50	51-60	61+
Educational Background	High school	Diploma	Bachelor's or equivalent level	Master's or equivalent level	Doctoral or equivalent level	
Discipline	Concept	Design	Execution	Management	Structural	Others
Position in your company	Researcher	Junior	Middle Level	Managerial	Executive	
Years of Experience	0-2	3-5	6-10	11-15	16-20	21+
To what extent do you agree/disagree with the following decision factors relevance to rating a contractor before the tendering phase						
Decision Factors	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Don't know
Commercial						
Cost						
Time-frame						
Financial Stability						
To what extent do you agree/disagree with the following decision factors relevance to rating a contractor before the tendering phase						
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Don't know
Technical						
Past Performance						
Quality rating of previous projects						
Completed similar project scale						
Safety ratings						
References						
Availability of staff for the project						

Equipment resources						
Relevant Experience						

APPENDIX B

Table 12: Sample from the Comma Separated Line File

Category Borough Managing_Agency Duration Total_Schedule Changes Delay_percentage Planned_Budget Total_Budget_Changes Actual_Budget Budget_Percentage Quality_Rating Past_Experience Safety_Rating Similar_project_Scale Fincial_stability Success_rate
Wastewater Treatment Brooklyn DEP 2304 79 3.43 182980960 -9736936 173244024 -5.32 5 8 5 3 9 85.38 5
Wastewater Treatment Queens DEP Construction 1654 324 19.59 63438806 13064304 76503110 20.59 2 2 6 2 10 59.96 5
Wastewater Treatment Queens DEP Construction 1905 324 17.01 66806759 13064304 79871063 19.56 3 5 9 4 7 69.69 5
Water Supply Carmel DEP Construction 5138 437 8.51 64285939 2979083 67265022 4.63 3 10 6 10 5 80.37 3
Sewers Queens DEP Construction 1917 -93 -4.85 37496218 -19625672 17870546 -52.34 5 5 5 8 8 97.44 5
Wastewater Treatment Brooklyn DEP Construction 4660 1609 34.53 198134067 29226109 227360176 14.75 5 4 9 1 10 74.14 5
Wastewater Treatment Queens DEP Construction 8069 1434 17.77 449449571 -14341168 435108403 -3.19 4 10 7 6 3 79.08 4
Water Supply Staten Island EDC Construction 4760 914 19.2 269614053 25965126 295579179 9.63 4 7 6 9 8 80.23 2
Parks Manhattan EDC Construction 1735 789 45.48 60000000 0 60000000 0 4 1 3 10 7 67.9 2
Parks Manhattan EDC Construction 2524 789 31.26 60000000 0 60000000 0 5 8 7 3 9 80.75 5
Parks Manhattan EDC Construction 4431 1461 32.97 169562946 18216708 187779654 10.74 2 10 6 5 10 70.26 2
Bridges Brooklyn DOT 2860 367 12.83 374745267 -26969866 347775401 -7.2 3 2 3 3 5 63.87 1 4
Ferries Brooklyn DOT 2047 -122 -5.96 331987273 83455477 415442750 25.14 5 4 3 5 9 77.16 5 3
Bridges Bronx DOT Construction 5956 717 12.04 200270457 91034457 291304914 45.46 3 5 4 10 8 67.5 3 3
Streets and Roadways Brooklyn DDC Design 5093 -1447 -28.41 58706000 55156000 113862000 93.95 3 10 9 2 6 65.89 1
Water Supply Manhattan DDC Design 2023 493 24.37 67610000 -18630298 48979702 -27.56 5 2 4 8 9 83.64 1
Streets and Roadways Bronx DDC Construction Procurement 5940 1995 33.59 130762000 106246000 237008000 81.25 4 2 3 0 6 44.03 2
Sewers Bronx DDC Design 1855 39 2.1 83801000 21357000 105158000 25.49 5 10 5 9 4 82.48 5
Sewers Bronx DDC Construction 2860 39 1.36 105228000 21357000 126585000 20.3 4 7 9 8 8 83.67 2
Water Supply Queens DDC Design 2001 1035 51.72 44838000 32342000 77180000 72.13 2 10 10 7 3 53.23 1
Streets and Roadways Brooklyn DDC Design 9897 1445 14.6 28787000 13928000 42715000 48.38 2 5 7 2 6 55.4 4
Streets and Roadways Manhattan DDC Construction Procurement 5953 669 11.24 2251510262 -181119 2251329143 -0.01 4 4 8 0 4 69.75 4
Sanitation Manhattan DDC Construction Procurement 2405 1198 49.81 40468019 6787374 47255393 16.77 3 5 10 6 10 69.68 5
Bridges, Streets and Roadways Manhattan EDC Design 1455 349 23.99 161871508 81523850 243395358 50.36 4 6 7 7 3 64.13 1

Wastewater Treatment Staten Island DEP Design 2353 685 29.11 87533000 -935000 86598000 -1.07 4 5 4 1 6 66.39 4
Sewers Brooklyn DDC Design 1421 701 49.33 41250000 13750000 55000000 33.33 3 7 10 5 3 60.47 4
Sewers Brooklyn DDC Construction Procurement 1421 689 48.49 47280551 26415947 73696498 55.87 3 3 4 5 5 48.13 3

Table 13: Sample from the Dataset File after cleaning the data

Category	Borough	Managing Agency	Duration (D)	Total Schedule Changes (D)	Delay percentage	Planned Budget	Total Budget Changes	Actual Budget	Budget Percentage	Quality Rating (1-5)	Past Experience (1-10)	Safety Rating (1-10)	Similar project Scale (1-10)	Financial stability (1-10)
Wastewater Treatment	Brooklyn	DEP	2304	79	3.43	1.83E+08	-9736936	1.73E+08	-5.32	5	7	6	7	9
Bridges	Brooklyn	DOT	3247	367	11.3	3.37E+08	-2.7E+07	3.1E+08	-8.01	4	9	4	6	5
Water Supply	Carmel	DEP	5031	437	8.69	66616435	2979083	69595518	4.47	5	8	5	8	9
Sewers	Queens	DEP	2010	-93	-4.63	57121889	-2E+07	37496217	-34.36	4	6	6	8	9
Parks	Manhattan	EDC	1735	789	45.48	60000000	0	60000000	0	4	7	5	6	5
Ferries	Brooklyn	DOT	1975	-122	-6.18	2.44E+08	83455477	3.28E+08	34.16	4	7	7	9	7
Bridges, Streets and Roadways	Bronx	DOT	2947	588	19.95	1.99E+08	1.45E+08	3.44E+08	72.87	4	6	6	8	4
Streets and Roadways	Queens	DDC	4173	650	15.58	72004000	10505000	82509000	14.59	3	8	6	6	6
Schools	Queens	SCA	1279	-25	-1.95	1.08E+08	7008397	1.15E+08	6.47	2	6	6	9	6
Sanitation	Brooklyn	DDC	1810	1202	66.41	29465000	13000	29478000	0.04	2	9	5	8	6
Libraries	Queens	DDC	1903	-143	-7.51	39000000	19860947	58860947	50.93	4	6	7	8	7
Arts and Culture	Manhattan	DDC	1902	484	25.45	1.04E+08	44275000	1.48E+08	42.76	4	8	4	6	7
Parks, Streets and Roadways	Queens	EDC	1608	549	34.14	28206030	9761917	37967947	34.61	2	8	6	9	6
Public Safety and Criminal Justice	Citywide	DOC	528	0	0	1.05E+08	-134936	1.05E+08	-0.13	2	7	8	8	4
Industrial Development	Brooklyn	EDC	663	659	99.4	43528000	1729000	45257000	3.97	4	8	4	6	4
Other Government Facilities	Brooklyn	DCAS	788	-196	-24.87	26607892	-680318	25927574	-2.56	4	7	6	7	4
Industrial Development, Streets and Roadways	Bronx	DDC	4363	-152	-3.48	36388366	-7251714	29136652	-19.93	3	6	7	9	4
Industrial Development, Public Safety and Criminal Justice	Queens	DOC	3366	0	0	29230000	0	29230000	0	3	7	8	8	6
Sewers, Streets and Roadways, Water Supply	Brooklyn	DDC	4855	36	0.74	26280000	0	26280000	0	3	8	6	8	5
Streets and Roadways, Water Supply	Queens	DDC	4351	0	0	63114450	0	63114450	0	4	7	6	9	4