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DIGITALIZATION AND TENDER EVALUATION IN CONSTRUCTION PROJECTS: A BIM-INTEGRATED MCDA APPROACH SUPPORTED BY MACBETH

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SUMMARY: *The tender evaluation process in the procurement for construction works, aligned with regulations such as the European Directive 2014/24/EU, faces various constraints, increasingly acknowledging the impact of digitalization, particularly through Building Information Modeling (BIM). Therefore, a thorough BIM-integrated multi-criteria decision analysis approach is vital to fairly select the best contractor for the job and ensure project success. Despite its significance, the literature remains scarce, particularly in addressing BIM-related and value-focused constraints for construction tender evaluation. This research introduces a comprehensive and value-focused method integrating BIM criteria through Multicriteria Decision Analysis (MCDA) supported by the Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH), which is applicable to both the public and private sectors, serving as a reference guide for contracting authorities to assess and select the best tender for BIM-based construction works contracts. For this purpose, the following methodology was adopted: 1) conducting an extensive literature review; 2) carrying out interviews with construction experts to identify BIM-integrated evaluation criteria and performance descriptors; 3) creating an adapted MCDA construction tender evaluation framework supported by MACBETH; 4) performing a real-world case study to demonstrate the proposed evaluation framework; 5) discussing its application and limitations, along with considerations for future research. The study demonstrated the practicality of the proposed framework through a case study, showing that a value-based approach can significantly improve project outcomes compared to traditional methods. While acknowledging the potential of the BIM methodology, the impact of BIM-specific criteria on contractor selection was found to be less significant than expected. In conclusion, this work addresses current limitations, such as the absence of BIM-integrated assessment guidelines in the European Directive 2014/24/EU and ISO 19650. It outlines a value-focused MCDA approach for evaluating tenders for construction works contracts, supported by MACBETH for structuring the decision problem and building the evaluation model. The contribution to the body of knowledge lies in providing a robust framework that enhances the evaluation process in BIM-based construction works contracts and offers practical insights for contracting authorities.*

KEYWORDS: *building information modeling (BIM), construction, european directive 2014/24/EU, measuring attractiveness by a categorical based evaluation technique (MACBETH), multicriteria decision analysis (MCDA), tender evaluation.*

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1. INTRODUCTION

In the construction industry, the methods used to assess and pick contractors have been mainly borrowed from those used in the public sector and have remained mostly the same (Lehtonen et al, 2022). These methods typically involve evaluating bids based on multiple criteria or only one criterion. The latter, where the contract is awarded to the lowest bidder, is the most used method, as it is often seen as the easiest way to achieve the best value for money (Lehtonen, et al 2022, Tavares, et al 2022b).

Despite this, many now agree that relying solely on bid price can cause several problems in project delivery. That approach can lead contractors to seek extra income through claims or cost reductions, which can have significant negative effects both technically and economically, affecting projects and organizations. That's why choosing solely based on the lowest bid is seen as very risky, especially from the client's point of view (Ellis et al, 1991).

This has prompted studies on multicriteria decision analysis to explore techniques for contractor selection that incorporate information regarding client objectives and contractor capabilities, along with bid price, as objectively and transparently as possible, as a way of achieving the best value for money (Fregonara, et al 2022, Macek, 2023). For reference, there have been the development of methodologies and frameworks based on multicriteria evaluation models for selecting contractors, by collecting preference information through interviews and questionnaire surveys to construction professionals using techniques such as the Delphi method; and by performing data analysis through methods such as the Program Evaluation and Review Technique (PERT) (Hatush et al, 1997), the utility theory (Hatush et al, 1998), the Analytic Hierachy Process (AHP) (Mahdi, et al 2002, Marović, et al 2021), and the Optioncards (Tavares et al, 2022a).

However, prior research has uncovered specific limitations, ranging from small sample sizes and restricted geographic scope to constraints in numerical methods and limited generalizability (Skitmore, et al 2001, Topcu, 2004). This highlights the need for additional research to address these gaps and enhance the knowledge on tender evaluation for contractor selection in the construction field.

One of the gaps lies in the omission of digitalization factors within evaluation frameworks, particularly the criteria related to Building Information Modeling (BIM), which is an increasingly important tool in the construction industry, and the examination of its impacts. Some studies have sought to address this by exploring the potential of BIM to enhance procurement processes through improved comprehension and heightened transparency (Russo, et al 2017, Park, et al 2022, Popov, et al 2021); by analyzing the correlation and implications of BIM in different contractual arrangements (Ariffin et al, 2017); by proposing a comprehensive approach for selecting contractors skilled in BIM and modern technologies (Mahamadu, et al 2017, Wang, et al 2019, Khoso, et al 2021, Popov, et al 2021); or by evaluating the post-selection performance of organizations in BIM-based projects through criteria for assessing their BIM capability (Mahamadu et al, 2020). Nevertheless, BIM-specific criteria are still lacking within general contractor evaluation frameworks and in value-focused multicriteria decision analysis (MCDA) approaches.

Another gap lies in the reliance on MCDA methods that predominantly use quantitative inputs (e.g. Analytic Hierarchy Process - AHP), despite the fact that, to the best of this paper author's knowledge, qualitative inputs are naturally more prevalent, especially in tender evaluation processes. While quantitative outputs are usually convenient for analysis and decision-making, individuals generally lean towards qualitative judgments, rather than quantitative assessments, when measuring the relative attractiveness of different options. Moreover, frequently employed methods often rely on alternative-focused approaches rather than value-focused ones, which can lead to suboptimal results when not adequately considering the values and preferences of the decision-making body. In this context, the Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) emerges as a suitable approach to support primarily qualitative and value-focused decision-making. Several studies, notably by Bana e Costa (e.g. Bana e Costa et al, 2002, 2012), who developed MACBETH (Bana e Costa et al, 1994), have focused on enhancing bid evaluation processes in public tenders using this method - despite its effectiveness, to the best of this paper author's knowledge, MACBETH has not been widely adopted, not only due to the technical proficiency required but also because it has not received sufficient commercial and technical dissemination internationally. However, none of these studies explored the use of this technique within a general evaluation framework for construction works, including BIM-specific criteria.

This paper aims to address the aforementioned gaps by introducing a comprehensive and value-focused method integrating BIM criteria through MCDA supported by MACBETH, which is applicable to both the public and private sectors, serving as a reference guide for contracting authorities to assess and select the best tender for BIM-based construction works contracts. To achieve this, the process involved an extensive literature review and a series of interviews with construction experts to identify BIM-integrated evaluation criteria and performance descriptors, followed by the development of a comprehensive BIM and MCDA-based construction tender evaluation framework supported by MACBETH. Subsequently, a real-world case study was conducted to demonstrate the proposed evaluation framework, comparing it to traditional practices. The study concludes by highlighting the practical benefits of the proposed framework, noting its effectiveness in improving project outcomes while recognizing the limited impact of BIM-specific criteria, and suggests further research to address gaps such as the lack of BIM-integrated guidelines in existing regulations.

Given that private procurement frequently lacks specific regulations and often relies on public sector standards, it is important to note that this paper is built upon principles derived from the European Directive 2014/24/EU (Directive, 2014), adapting these guidelines to develop a robust framework applicable to both public and private sectors.

That said, the paper is organized as follows: section 2 outlines the research methodology; section 3 reviews the relevant literature on public procurement and evaluation practices, including BIM, MCDA, and MACBETH; section 4 introduces the proposed decision-making model; section 5 analyzes the case study; and, finally, section 6 summarizes the main findings, discusses the study's limitations, and establishes directions for future research.

2. RESEARCH METHODOLOGY

The applied research methodology consisted of four main steps, which are represented in **Figure 1** and described in the following subsections.

Research phases	Literature review	Interviews	MCDA tender evaluation framework	Case study
Key steps	**1)** Perform comprehensive search using recognized data search engines; **2)** Apply inclusion criteria: relevance, quality, BIM advancements; **3)** Apply exclusion criteria: non-peer-reviewed, outdated, not construction-focused.	**1)** Select 15 experts with over 10 years of experience; **2)** Conduct interviews via in-person and virtual sessions; **3)** Value identification; criterion elicitation; performance descriptors.	**1)** Define decision problem; **2)** Select MCDA method (MACBETH); **3)** Build consensus with experts.	**1)** Select BIM-based project; **2)** Collect project data; **3)** Apply MCDA framework with MACBETH; **4)** Analyze and compare results.

Figure 1: Research methodology process.

2.1 Literature review

This research conducted a systematic literature review to examine public tender processes, methodological constraints, existing evaluation practices, and the role of BIM in construction tender evaluations. A structured approach was employed in the review process, which involved several key steps to ensure thoroughness and rigor.

First, a comprehensive search was performed using well-established academic databases namely "google scholar", "scopus", and "web of science". This was followed by a detailed selection process where inclusion criteria included relevance to the topic of construction tender evaluation, methodological quality, and recent advancements in BIM integration. Studies were excluded if they were not peer-reviewed, outdated, or did not fit the specific focus of construction tenders.

This approach ensured that the review was systematic and comprehensive, covering a broad range of relevant literature while maintaining high standards of quality and relevance. This process allowed for the identification of key research gaps and areas for innovation, which were instrumental in shaping the subsequent phases of the study.

The literature review begins in section 1, where several studies on MCDA and MACBETH, as well as the impact of BIM criteria within tender evaluation frameworks, are discussed. This section highlights the limitations of these studies and explains how the present research contributes to the existing body of knowledge.

In section 3, the literature review is expanded to focus primarily on the European Directive 2014/24/EU (Directive, 2014), which serves as the foundation for this study. This section describes the public tender process, its methodological specifics, and current evaluation practices, followed by an overview of BIM methodology in the context of construction contracts. Additionally, a separate subsection on MCDA and MACBETH is included.

2.2 Interviews

The interview methodology employed a systematic and structured approach designed to capture essential insights from experienced construction professionals, similar to the one utilized in the research conducted by (Matos et al, 2024). This method was carefully organized to ensure comprehensive coverage of critical evaluation criteria for BIM-based construction tenders and the establishment of precise performance benchmarks.

The interviews were conducted through a combination of in-person meetings and virtual sessions, utilizing platforms such as “zoom” and “microsoft teams” to facilitate participation from a diverse range of locations. A total of 15 experts were selected based on their extensive experience in construction tender evaluation and expertise in BIM technologies. The selection process involved reaching out to industry leaders and practitioners through professional networks and industry conferences, ensuring a broad representation of viewpoints. The experts included senior project managers, procurement specialists, and BIM consultants, each with over 10 years of experience in their respective fields. Their diverse backgrounds provided a well-rounded perspective on the evaluation criteria and performance benchmarks needed for BIM-based construction tenders.

The structured interview process comprised three key stages:

1) Value identification: experts provided their perspectives on the primary drivers of value in construction projects. This stage aimed to establish a foundational understanding of what constitutes value from an industry standpoint.

2) Criterion elicitation: based on the identified drivers of value, experts specified the screening and evaluation criteria essential for assessing tenders within a BIM environment. This stage focused on capturing a value-focused approach to tender evaluation.

3) Performance descriptors: experts articulated performance benchmarks for each evaluation criterion, distinguishing between "good" and "neutral" outcomes. These benchmarks were designed to facilitate an objective assessment of how well tender proposals meet the established criteria.

The outcome comprised a comprehensive criteria evaluation framework (**Appendix 1**) along with the corresponding value tree (**Appendix 2**).

2.3 MCDA tender evaluation framework

This part of the research involved tailoring the well-regarded MCDA approach to the specific context of construction tender evaluation. The adaptation process was carried out through the following steps

1) Decision problem: defining the decision problem specific to construction tender evaluation, drawing on the previous interviews and the paper authors' expertise;

2) MCDA supporting method: MACBETH was selected to support the implementation of MCDA, given its potential in effectively managing qualitative information, as further elaborated in section 4;

3) Consensus building: engaging with the previously involved experts to align the adapted MCDA approach with the industry's objectives and values through a consensus-building process.

This resulted in the creation of a construction tender evaluation framework, which is elaborated in section 4 and illustrated in **Figure 3**.

2.4 Case study

The research methodology concluded with the application of the proposed MCDA tender evaluation framework to a real-world case study. This step aimed to validate the framework and assess its effectiveness compared to traditional evaluation practices.

The analysis was conducted through the following steps:

1) Selection of case study: the case study was selected based on specific criteria to ensure its appropriateness and relevance for evaluating the proposed framework. The criteria included the following:

-**Relevance to BIM**: the project had to be BIM-based to align with the framework's focus on BIM integration;

-**Complexity and scale**: the project needed to be sufficiently complex to test the framework's ability to handle diverse evaluation criteria and real-world conditions;

-**Availability of data**: the project required accessible data, including tender proposals and performance records, to apply and test the MCDA framework effectively.

2) Data collection: for the selected project, detailed data was gathered, including:

-Tender proposals: the various proposals submitted for the project were collected to provide a basis for evaluation;

-Project documentation: all relevant project documents were compiled to understand the context and requirements;

-Historical performance records: data on past project performance was collected to provide benchmarks and context for the evaluation.

3) Application of the MCDA framework: the MCDA framework was applied to the collected data using the MACBETH-specific software system. The framework utilized the evaluation criteria specified in **Appendix 3**, which were derived from the foundational criteria detailed in **Appendices 1 and 2**. This step involved:

-Evaluating tender proposals: each proposal was assessed based on the BIM-integrated criteria to determine its performance and value;

-Applying criteria: the criteria from **Appendices 1 and 2** were used to structure the evaluation process and ensure consistency.

4) Result analysis: the results obtained from applying the MCDA framework were analyzed and compared with outcomes from traditional evaluation practices used for the same tender proposals. This comparison aimed to:

-Validate the framework: assess the effectiveness and accuracy of the MCDA approach compared to traditional methods;

-Demonstrate potential benefits: highlight any advantages of the MCDA framework in providing a more comprehensive and objective evaluation.

This final phase of the research aimed to validate the adopted methodology and demonstrate the transformative potential of the proposed evaluation framework in the context of tender evaluations for BIM-based construction contracts.

3. LITERATURE REVIEW

The award of construction contracts, especially within the realm of public procurement, typically entails a tender evaluation analysis that considers principles such as non-discrimination, proportionality, and transparency.

The process of selecting the optimal tender, as outlined in European Directive 2014/24/EU (Directive, 2014), can be undertaken through one of the following methods: mono-criterion (the lowest price) and multi-criteria evaluation.

The latter enables the consideration of additional factors beyond price, fostering the use of multi-criteria evaluation methods. To achieve this, CA must establish criteria that collectively identify the most economically advantageous tender.

In this sense, European Directive 2014/24/EU not only mandates the advance disclosure of the criteria but also requires the specification of the relative weight assigned to each criterion. This enables tenderers to consider this information while preparing their tender proposals, thereby adhering to principles such as transparency.

In countries like Portugal, through the Portuguese Code of Public Contracts (Decree-Law, 2008), the tender evaluation requirements are more stringent, necessitating not only the identification of criteria and their weights but also the specification of the scoring rules.

3.1 Public tender process

As outlined in the European Directive 2014/24/EU (Directive, 2014), various approaches can be taken when awarding contracts for public construction projects. These approaches encompass direct assignment of contracts, inviting bids based on prior qualifications, or conducting a public tendering process. The choice of the most appropriate procedure is influenced by factors such as the estimated contract value, project complexity, the nature of the works, the necessity for ensuring fair competition, and the urgency to complete the project.

Among these procedures, according to this paper author’s experience, opting for a public tender is a common choice. However, it is governed by specific regulations and must conform to a distinct set of rules and procedures outlined by governing authorities. The general procedure for public tenders is described below.

Firstly, it is crucial to delineate the contract's scope, encompassing details like the design of the construction project.

Subsequently, it becomes necessary to articulate the supply conditions through a comprehensive specifications document, explicitly detailing the requirements, including obligations and responsibilities for both the contractor and the CA. This specifications document typically consists of two primary sections: general clauses covering administrative aspects such as deadlines, payment terms, and insurance requirements, and special clauses addressing the more technical aspects of executing the construction works.

Lastly, the tender document must be prepared, establishing the framework for managing the tender process. This involves specifying conditions, deadlines, and the format for submitting proposals.

These documents constitute parts components of the invitation to tender, officially initiated through a public announcement. Throughout the bidding process, tenderers can submit requests for information, that will be addressed by the CA.

Upon receiving the proposals, a public event is convened to open them, overseen by a committee appointed by the CA, known as the opening committee. This committee assesses the qualifications of competitors and the content of their proposals by cross-referencing the submitted documents, until a final decision is reached.

Following this step, the evaluation committee, previously appointed by the CA, begins its work, which is divided into two phases: the selection phase, involving the application of screening criteria, and the contract award phase, where evaluation criteria come into play. The selection phase includes a pre-qualification stage aimed at excluding firms that do not meet pre-established financial and/or technical requirements. The contract award phase serves as the pivotal stage.

The evaluation committee may collaborate with experts specializing in the technical analysis of proposals and may seek clarifications from competitors regarding any uncertainties in the interpretation of submitted materials. Additionally, they may gather information from external sources to assess the actual financial and technical capabilities of competitors.

Mandated to support their analysis, the evaluation committee generates evaluation reports that are distributed to all competitors for their feedback.

After receiving and analyzing competitors' comments, the committee formulates a final proposal for submission to the CA, marking the completion of the committee's role in the process.

Following this stage, crucial steps unfold until the contract is awarded, but these are not addressed here as they extend beyond the evaluation phase.

The public tender process described above is depicted in **Figure 2**.

Procurement phases	Invitation to tender	Tender response	Tender evaluation	Contract award
Procurement Procedures	Tender and Specifications documents Public announcement	Requests for information Opening of proposals	Screening and evaluation	Negotiation
Main authors	Contracting Authority	Tenderer Opening Commitee	Evaluation Committee Contracting Authority	Contracting Authority Selected tenderers

Figure 2: Public tender process.

3.2 Methodological particularities

In line with the foundational principles of transparency and competition, the evaluation process must be explicitly outlined in the tender documents right from the beginning, ensuring that competitors understand the “rules of the game” (Directive, 2014).

Thus, the complete evaluation model must be made public beforehand, without the possibility of any subsequent modifications. This safeguards bids from being evaluated based on undisclosed factors.

This mandate, in accordance with European Directive 2014/24/EU, extends to disclosing the contract award criteria, their relative weights, and, contingent on local regulations, the associated scoring functions.

The criteria chosen for evaluation should solely address aspects relevant to the competitive scope, closely aligning with the objectives and specifications outlined by the CA. These criteria shall avoid any direct or indirect reference to competitor-specific situations, qualities, or characteristics.

Once these criteria are established, the scoring rules are defined. These rules, whether expressed mathematically or through a defined set of performance levels, should not rely on comparisons with other tenders, avoiding relative scoring functions such as those based on lowest or average prices.

The accurate determination of the relative weights relies on assessing the potential impact of variations on the criteria. However, according to this paper author’s experience, this determination is typically contingent on information available after bid unveiling, unless an alternative method, such as previously establishing weights based on performance references, is employed. This method is further elaborated upon in section 4, specifically in section 4.3.

The overall score of each tender is calculated by multiplying the partial scores, determined through the scoring functions assigned to each criterion, by their respective weights.

3.3 Current evaluation practices

Competitive bidding stands as the most used procedure for selecting the best contractor for construction works, primarily relying on the lowest price as the sole criterion for contract award (Hatush et al, 1998).

However, relying solely on the lowest bidder might not be the most cost-effective choice in the long term, as it poses risks such as poor contractor performance, financial issues, project delays, and substandard quality. Thus, more comprehensive evaluation methods should generally be adopted, considering these risks by examining non-price-related data.

While MCDA methods exist for this purpose, several challenges arise, including the difficulty of assigning weights to vaguely defined criteria and scores to proposals without specific, value-focused scoring functions.

One of the most common mistakes in construction procurement is assigning quantitative weights to criteria solely based on the CA's perception of their relative importance, which may lead to discrepancies in optimal preferences.

For instance, let's consider a scenario where a tender priced at 20 million euros with a completion time of 24 months is favored, due to price weighting, against another one priced at 21 million euros but with a shorter completion time of 18 months. Does the tender with the lower price truly align with the CA's optimal preferences? Alternatively, would the CA be willing to pay an additional 1 million euros (5% increase) for a reduction in completion time of 6 months (25% decrease)?

This conventional approach might significantly deviate from the CA's actual preferences.

A solution to address this problem is proposed in section 4, specifically in subsection 4.5.

3.4 BIM

Building Information Modeling (BIM) can be defined as "the use of a shared digital representation of a built asset to facilitate design, construction, and operation processes to form a reliable basis for decisions" (CEN, 2018b). In practical terms, according to this paper author's best knowledge, BIM utilizes advanced information technologies to create and manage three-dimensional models that can incorporate all pertinent data on built assets throughout their lifecycle. This methodology addresses inefficiencies of traditional processes, which are characterized by a lack of cohesion and reliance on conventional paper-based methods and two-dimensional file formats. The absence of collaboration and standardization in traditional methods often leads to errors, omissions, and incompatibilities, resulting in conflicts, delays, and cost overruns, especially during the construction phase.

Some countries are already mandating the use of BIM for specific types of public construction projects, including Finland, Sweden, the UK, France, Italy, and Russia (McAuley et al, 2017). Others, such as Germany and Spain, are actively implementing BIM programs with the intention of enacting future mandates (Popov et al, 2021; Garcia et al, 2021). However, certain countries like Portugal, Switzerland, and Belgium currently have no planned BIM mandates. Consequently, the implementation of BIM, especially across Europe, remains notably fragmented.

The European Directive 2014/24/EU suggests that member states may consider mandating the use of specific electronic tools such as BIM or similar innovative methods in public procurement to foster innovation, which is deemed crucial for future growth in Europe. However, this directive does not impose specific mandatory BIM requirements for construction works contracts nor directly influence the tender evaluation process concerning BIM criteria. Similarly, European Union countries like Portugal, where local legislation is primarily derived from European directives, do not explicitly incorporate detailed BIM considerations into their public legal frameworks.

Nevertheless, according to the standard ISO 19650-2 (CEN, 2018b), BIM should be integrated as far as possible with existing processes for technical procurement. Therefore, during the preparation of the bidding documents, the CA shall consider the necessary BIM evaluation requirements.

While the standard provides general recommendations for BIM-specific workflows and documentation, including the reference to the need for evaluating tenderer capabilities, it does not offer guidance on conducting a BIM-based tender evaluation process. This is an area where this study provides valuable insights.

Although this paper does not delve into the whole BIM-based procurement methodology, with ISO 19650-2 as a reference, it is important to note that BIM commercial, managerial, and technical requirements (Exchange Information Requirements or EIR) should be integrated into the bidding documents, especially the specifications document, laying the foundation for BIM-integrated evaluation procedures that are outlined in coherence with those requirements in the tender document. Subsequently, tenderers are expected to respond to these requests by providing specific documents such as the BIM Execution Plan (BEP) and the Master Information Delivery Plan (MIDP), along with additional documentation to support the evaluation of BIM qualifications, experience, and organizational structure, which may include team curricula, project portfolio, organizational and project charts, and recommendation letters.

3.5 MCDA and MACBETH

MCDA represents a comprehensive approach encompassing diverse supporting methods for decision-making. It aims to curb biases and subjectivity by offering a structured framework to assess and compare various alternatives based on their performance across multiple criteria. This facilitates decision-makers in arriving at more informed and objective conclusions.

MCDA becomes especially relevant when dealing with multifaceted issues such as tender evaluation, particularly within public procurement. In this context, it addresses the imperative to justify evaluation choices and judgments while upholding principles of fairness and transparency in allocating public resources. Additionally, it responds to the requirement of setting the evaluation rules completely beforehand.

Construction tender evaluation involves criteria spanning quantitative and qualitative aspects measured on different scales. This can be resolved through the Multi-Attribute Value Theory (MAVT), which enables decision-makers to compare alternatives using a unified metric (Belton et al, 2003), enhancing systematization, transparency, and precision, while preventing the risk of rank reversal (Wang et al, 2009).

MACBETH is a method compatible with MAVT and is particularly useful over other numerical methods for building construction tender evaluation models. Specifically, one of the main reasons for this preference is that MACBETH relies on qualitative judgments, considering the preferences of the decision-making body. These judgments are then used to quantify the relative values of options, forming the foundation for building the scoring functions and assessing weighting coefficients. The theoretical foundations of MACBETH can be found in (Bana e Costa et al, 1994, 2012).

The MACBETH method stands out by addressing the gap in MCDA methods that primarily rely on quantitative inputs, whereas qualitative inputs are naturally common, particularly in tender evaluation processes. While quantitative outputs are usually convenient for analysis and decision-making, according to this paper author's best knowledge, individuals generally lean towards qualitative judgments rather than quantitative assessments when measuring the relative attractiveness of different options.

Moreover, frequently employed methods often rely on alternative-focused approaches rather than value-focused ones, potentially leading to suboptimal results when not adequately considering the values and preferences of the decision-making body. In this context, MACBETH emerges as a suitable approach to support primarily qualitative and value-focused decision-making. Several studies, notably by Bana e Costa (e.g. Bana e Costa et al, 2002, 2012), have focused on enhancing bid evaluation processes in public tenders using this method.

Despite its effectiveness, MACBETH has not been widely adopted, primarily due to the technical proficiency required and insufficient commercial and technical dissemination internationally. The MACBETH software provides a practical tool for implementing the MACBETH method, facilitating its application in real-world scenarios. This software aids in the systematic capture and processing of qualitative judgments, translating them into quantitative values for comprehensive decision analysis.

All in all, MCDA and MACBETH provide robust frameworks for construction tender evaluation, addressing both quantitative and qualitative criteria. The MACBETH software enhances the practical application of these methods, promoting fairness, transparency, and precision in procurement processes. The integration of these methodologies can lead to more informed and objective decision-making, ultimately improving the allocation of resources in construction projects.

4. TENDER EVALUATION USING MCDA

The proposed MCDA tender evaluation framework is depicted in **Figure 3**. Each step of this framework is further described in the following subsections, considering the same numbering.

A practical demonstration of this method is presented in section 5.

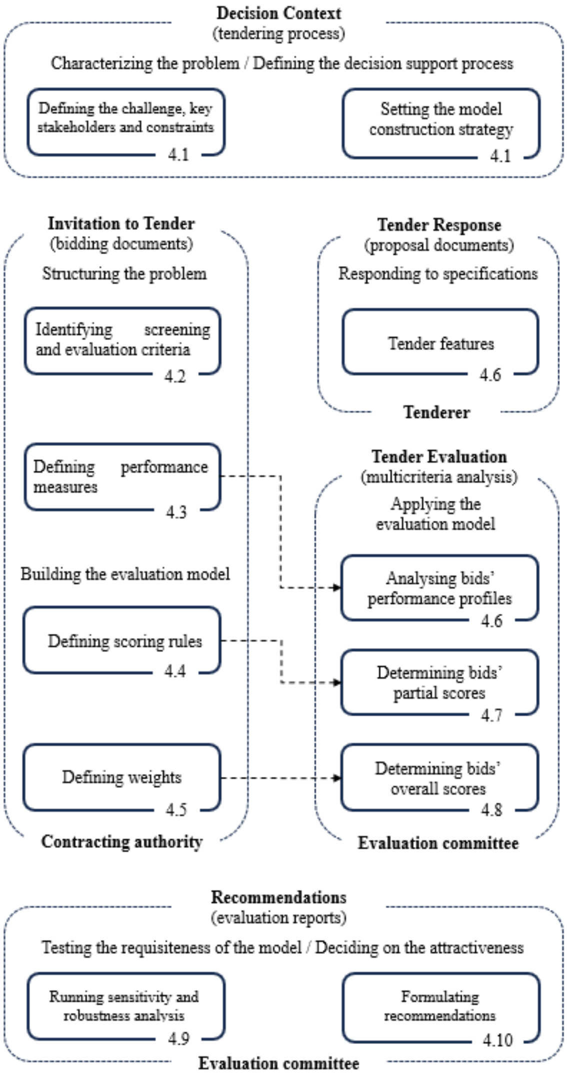

Figure. 3: MCDA tender evaluation framework - adapted from (Mateus et al, 2010).

4.1 Decision context

This phase involves comprehending the tendering process, its stakeholders, and methodological limitations. It includes establishing the decision support process and system and defining the evaluation model type.

While these aspects have been addressed earlier in this paper, they should be tailored on a case-by-case basis, considering the contract scope, available resources (e.g. time and money), and other constraints such as legal and environmental factors.

4.2 Identifying screening and evaluation criteria

The process of identifying criteria is particularly relevant for two main reasons. Firstly, it plays a crucial role in establishing and validating the concept of the "best tender" from the CA's perspective. Secondly, it is essential in ensuring that all criteria are disclosed alongside procedural documents.

In this context, employing a value-focused thinking methodology proves beneficial as it centers on CA objectives through Fundamental Points of View (FPV), which are derived from interactive methods involving key stakeholders. These FPV serve as a bridge for translating objectives into criteria, considering key principles such as isolability, non-redundancy, completeness, conciseness, operationality, measurability, lack of ambiguity, and consensus (Keeney, 1992).

In tender evaluation, criteria are usually categorized into screening and evaluation types. While screening criteria establish admissibility or pre-qualification thresholds related to the tenderer's capacity, the evaluation criteria concentrate on the attributes of the tender proposal. These criteria are typically organized in a hierarchical structure represented by a value tree.

A BIM-integrated framework featuring both screening and evaluation criteria - determined according to the research methodology described in section 2 - is presented in **Appendix 1**. The corresponding value tree is represented in **Appendix 2**.

The utilization of this framework should be adapted on a case-by-case basis.

One aspect to highlight is the expected performance criteria, which provides an alternative to past performance in terms of assessing the tenderer's credibility in executing the contract according to the accepted tender proposal (Tavares et al, 2013). While past performance assessment can be admissible in countries like the United States (Albano et al, 2011), it is viewed as potentially discriminatory in the European Union, according to the European Directive 2014/24/EU.

Additionally, the framework stands out by offering BIM-specific criteria for conducting evaluations at both the bid and bidder levels.

4.3 Defining performance measures

Performance measures, also known as descriptors of impacts or descriptors of performance, are used to operationalize each criterion by establishing plausible performance levels on a quantitative or qualitative scale. This approach is crucial to facilitate an objective assessment of each tenderer and tender proposal's performance concerning a specific criterion, ensuring comparability between different alternatives (Mateus et al, 2010).

For each performance measure, it is important to establish reference levels of intrinsic value, which will serve as comparison points for evaluating alternatives on each criterion independently of other tender features - “good” as the unequivocally attractive level and “neutral” as a level devoid of specific attractiveness. For instance, a proposal might be rated as “very good” if it surpasses the “good” level, “positive” if it falls between “neutral” and “good”, or “negative” if it falls below “neutral”.

This approach enables an assessment of the inherent attractiveness of each proposal and aligns with the specific requirements of public procurement, ensuring that the evaluation of one proposal is not influenced by the attributes of other proposals. It also helps to avoid scenarios where a bid is selected simply because it is the best among those submitted, even if it is inadequate in responding to the CA's preferences.

The performance references for the proposed BIM-integrated evaluation framework are also detailed in **Appendix 1**. These descriptors are qualitative by nature but can be adaptable to quantitative measures depending on the context (e.g. price and time).

4.4 Defining scoring rules

Scoring rules play a vital role in assessing tenders on each elementary criterion by converting the established performance levels into numerical scores. These scores gauge the relative attractiveness of each performance level, mirroring the CA's preferences. There is a need to avoid relative scoring functions, ensuring that assessments solely reflect CA priorities, irrespective of tenderers and their features - a fundamental requirement in public procurement.

The formulation of scoring rules predominantly hinges on the nature of performance measures - whether they are quantitative and continuous or qualitative and discrete. Respectively, these rules can be devised through mathematical expressions, such as the bisection method (Goodwin et al, 1997), or based on a predefined ordered set of performance levels, as exemplified in direct rating methods (Winterfeldt et al, 1986).

Particularly for performance measures of a qualitative nature, as the ones detailed in **Appendix 1**, MACBETH emerges as a suitable approach due to its adaptability to qualitative judgments, as previously explained.

4.5 Defining weights

Weights act as scaling factors for converting partial (local) scores from various criteria into an overall score.

In the context of the compensatory additive aggregation method, commonly used in public tender evaluations, weights essentially indicate the trade-offs between different criteria's partial scores. In other words, they represent how much the CA is willing to balance a decrease in one criterion against an improvement in another.

Determining these weights requires careful consideration of the performance levels for each criterion to ensure that they are not arbitrary or mistakenly interpreted as indicating the relative importance of criteria; rather, they should accurately mirror the true preferences of the CA.

For this reason, robust weighting procedures rely on structured questioning methods involving pairwise comparisons among performance levels of hypothetical reference tenders. These references can be simulated with the two distinct anchor impacts previously described for each criterion ("good" and "neutral"), as they do not depend on tender-specific features.

This methodology effectively addresses the challenge posed by the European Directive 2014/24/EU in determining weights prior to having bid knowledge.

Prominent weighting protocols include swing weighting (Winterfeldt et al, 1986), the trade-off procedure (Keeney et al, 1976), and MACBETH (Bana e Costa et al, 2000).

Once again, for the same reasons previously outlined, MACBETH stands out as a suitable method in supporting the weight definition, as described in (Bana e Costa et al, 1994).

4.6 Analysing bids' performance profiles

Once tender proposals are submitted, the evaluation phase commences.

Led by an evaluation committee, this phase involves scrutinizing the tender performances. The committee assesses the specific attributes presented by the different bidders against the predefined performance references for each aspect of the contract open to competition. This task demands technical expertise, and occasionally, external consultants are engaged to provide additional support.

The analysis outcome leads to the formulation of impact profiles for the various bids. These profiles lay the groundwork for determining the respective partial scores of the tenders.

This step marks a critical transition from the planning phase, which involves structuring the problem and building the evaluation model, to the execution phase, where the evaluation model is applied.

4.7 Determining bids' partial scores

Following the tender performance analysis, the evaluation committee allocates a partial score to each tender for every elementary criterion. This allocation is based on the previously defined scoring rules, either through a mathematical expression or by utilizing a score scale.

The scores are then meticulously verified to ensure they accurately reflect the value judgments made by the evaluation committee on behalf of the CA.

4.8 Determining bids' overall scores

The overall score for each submitted tender is computed using an additive value model, in accordance with the public procurement specifications outlined in European Directive 2014/24/EU.

This procedure, represented by **Equation 1**, involves summing up all partial scores on each elementary criterion, multiplied by their relative weights.

$$V(p) = \sum_{i=1}^{n} \mathrm{k}_i \mathrm{v}_i(p) \ , with \sum_{i=1}^{n} \mathrm{k}_i = 1 \ and \ \mathrm{k}_i > 0 \ and \begin{cases} \mathrm{v}_i(\mathrm{good}_i) = 100 \\ \mathrm{v}_i(\mathrm{neutral}_i) = 0 \end{cases} \tag{1}$$

where $\mathrm{v}_i(p)$ represent the partial values of each bid p for the criteria ($i = 1, \dots, n$); k_i the weighting coefficients; and $V(p)$ the overall value of bid p considering all n criteria. If sub-criteria are present, the procedure is initially applied to each group of sub-criteria that share the same parent criteria.

The additive aggregation procedure not only organizes bids based on their overall value but also assesses their relative differences in attractiveness. This approach involves utilizing cardinal preference information (v_i as cardinal scales), where decision makers establish value differences through judgments. This is very important because employing ordinal information in evaluation could result in inconsistent judgments, leading to the dependency of irrelevant judgments and, consequently, inaccurate decisions (Bana e Costa et al, 1994).

4.9 Running sensitivity and robustness analysis

Decision-making often involves grappling with incomplete, imprecise, or uncertain information. Therefore, it is crucial to explore the extent to which conclusions can be drawn under varying degrees of information availability, imprecision levels, or uncertainties.

Sensitivity and robustness analyses emerge as pivotal steps in evaluating the adequacy of the assessment model, focusing on its representation and consistency to effectively underpin decision-making.

Sensitivity analysis gauges how the model's outcomes react to fluctuations in judgments, performances, scores, or weights, while robustness analysis identifies dominant scenarios by comparing different alternatives using either ordinal or cardinal information.

This phase of the evaluation process is critical for validating results and formulating robust recommendations for selecting the most suitable contractor for the job.

4.10 Formulating recommendations

At this point, the evaluation committee issues its recommendations through duly justified evaluation reports.

The CA subsequently analyzes these reports, decides on the attractiveness of the various tender proposals, and appoints a party to award the contract.

5. CASE STUDY: OFFICE BUILDING IN LISBON

5.1 Decision context

This case study pertains to one of the most emblematic office buildings in Lisbon.

The construction works contract was awarded to a certain contractor. However, the tender evaluation process had been conducted using an alternative-focused approach, which might have overlooked the CA's value preferences, alongside traditional evaluation methods, that could have erred in criteria identification, scoring and weighting definition.

More recently, this situation had prompted the question of whether utilizing a value-focused tender evaluation through an MCDA approach, supported by MACBETH and aligned with the principles of public procurement as defined in European Directive 2014/24/EU, would have resulted in a different contractor to execute the contract.

In this context, the present case study aims to simulate a new evaluation process using the MCDA tender evaluation framework proposed in this paper and compare the original results (without MCDA) with the new simulated outcomes (with MCDA). This also serves to demonstrate the application of the new methodology as outlined in section 4.

To ensure consistency and comparable results, the decision-making body in the new evaluation process was identical to that of the original process. It comprised two managers from the contracting authority, as well as two senior construction project management consultants, one junior construction project management consultant, and two BIM consultants. The selection criteria for these decision-makers were based on their expertise and roles in the original evaluation process. Specifically, the two managers were chosen for their positions within the contracting authority, ensuring that the investor's interests were represented. The external consultants were selected for their experience and varying levels of seniority in construction project management, with the addition of two BIM consultants to provide specialized expertise. While the demographic details of the decision-makers - such as age, gender, and specific background information - are not specified in this study, it is assumed that their diverse perspectives contributed to a well-rounded evaluation process.

5.2 Decision-making without MCDA

Table 1 outlines the adopted evaluation criteria and their corresponding weights - the scoring rules ranged from 1 to 5, where 1 means poor performance and 5 signifies excellent performance. The screening criteria considered the bidder's financial health and bid project constraints (cost and time).

Table 1. Decision-making without MCDA: evaluation criteria and (total) assigned weights.

Area of concern	Criteria	Total weights
Bid Financial (bid)	Overall Price, Errors & Omissions, Exclusions, Alternatives, Payment Conditions	30 %
Bid Schedule (bid)	Overall Time, Work program, Equipment and Manpower	20 %
Bid Technical (bid)	Technical Report, Management Systems Plans (Quality, Environment, Safety)	15 %
Technical Ability (bid)	Organizational Structure, Personnel Qualification	15 %
Experience Record (bidder)	Number of Years and Total Work Volume in Similar Projects and Construction in general	15 %
BIM (bid and bidder)	Bid: overall price, BEP, MIDP, personnel, software; Bidder: experience, personnel	5 %

From the initial pool of five competitors, only four (A, B, C, D) advanced beyond the screening stage, with competitor E falling short due to exceeding the total cost limit by over 10%.

The subsequent evaluation stage using the classical additive aggregation model yielded the following ranking: 1) C (3.75), 2) B (3.50), 3) A (3.30), and 4) D (3.05). In the negotiation stage, proposal D was removed, refining the shortlist to: 1) C, 2) B, 3) A. Ultimately, proposal C secured the winning bid.

5.3 Decision-making with MCDA

5.3.1. Structuring the problem

Screening and evaluation criteria

The screening criteria, as outlined in **Appendix 1**, were employed during the pre-qualification phase.

The evaluation criteria described in **Appendix 1** were adapted for the current case, leading to the construction of the value tree depicted in **Appendix 3**. This adaptation involved a series of interactions with the original decision-making body, following the methodology previously described for outlining **Appendix 1**.

Performance levels

The performance references "good" (A5) and "neutral" (A2), as detailed in **Appendix 1**, served as benchmarks for establishing the remaining performance levels: "very good" (A6, above "good"), "moderately positive" (A4, between "neutral" and "good" but leaning towards "good"), "weakly positive" (A3, between "neutral" and "good" but leaning towards "neutral"), and "negative" (A1, below "neutral").

5.3.2. Building the evaluation model

Scoring

The scoring scale for each criterion was established through a meticulous application of the MACBETH questioning procedure.

This procedure involved the original decision-making body providing verbal judgments to assess the relative attractiveness between the various pairs of performance levels using the MACBETH semantic categories (A1 to A6). These judgments were meticulously recorded in separate matrices for each criterion.

The MACBETH software system played a crucial role in capturing these qualitative judgments, automatically evaluating their consistency, and subsequently translating them into value functions specific to each criterion. In this conversion process, the performance references “neutral” and “good” were anchored with the numerical values of 0 and 100.

As an example, **Figure 4** illustrates the judgment matrix and the resulting value function for the “overall price” criterion.

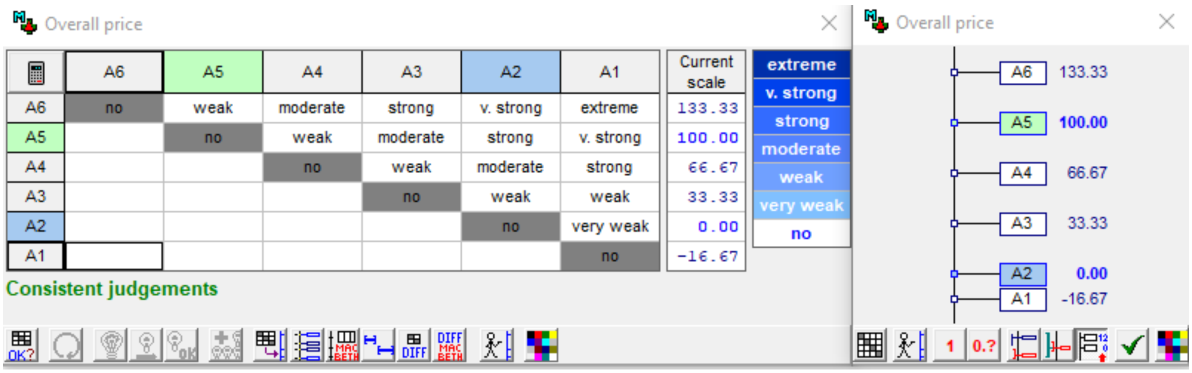

Figure 4. Judgement matrix and value function for the criterion “overall price”.

As an additional validation step, every scoring scale underwent a manual consistency check by the decision-making body, ensuring alignment with the group's preferences and logical combination of judgments.

Weighting

Based on the MACBETH weighting approach, criteria were weighted through pairwise comparisons to determine their relative importance.

In this sense, the decision-making group assessed 27 hypothetical options (corresponding to the total criteria depicted in **Appendix 3**). They ranked these options according to their overall attractiveness, considering the scenario of enhancing a bid from the worst ("neutral") to the best ("good") plausible performance levels.

Once the group ranked all 27 swings, they verbally evaluated the differences between each pair using the MACBETH semantic categories (A1 to A6).

This comprehensive process resulted in an ordering matrix of criteria and calculated scaling constants, as illustrated in **Figure 5**.

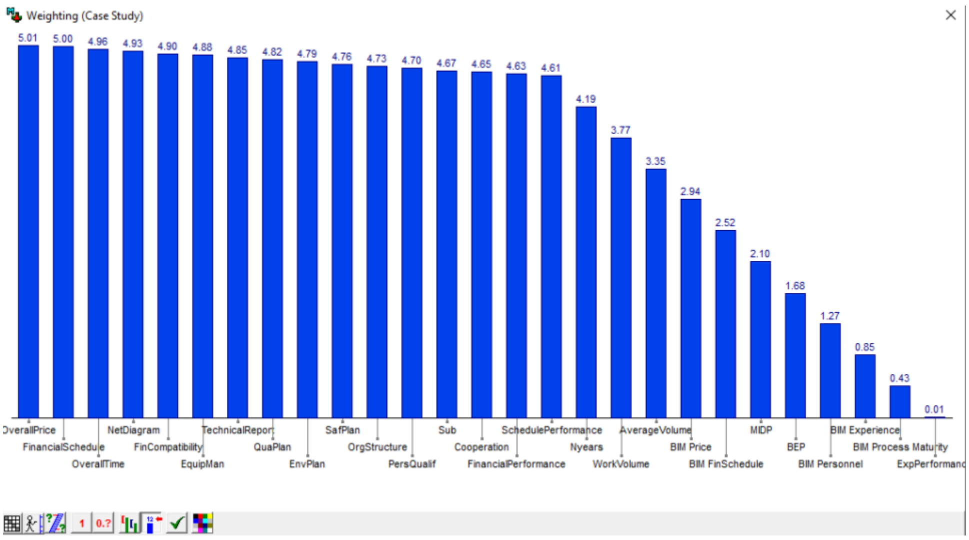

Figure 5. Criteria weights.

The decision-makers validated all results, including the additional check of every judgment inconsistency previously handled automatically by the software system.

Table 2 presents a comparison of the resulting total weights both with and without MCDA across the different areas of concern. The total weights with MCDA are derived from the rounded summation of weights obtained for respective criteria (as represented in **Figure 5**) following the logic outlined in **Table 1**. For instance, in the "Technical Ability" category, criteria encompass organizational structure ("OrgStructure", 4.73%), personnel qualifications ("PersQualif", 4.70%) and subcontractors ("Sub", 4.67%) - combining these weights results in a rounded total of 14%.

Table 2. Total weight comparison with vs. without MCDA (rounded values).

Area of concern	**with MCDA**	**without MCDA**	**absolute difference** (with-without)
Bid Financial (bid)	10 %	30 %	-20 %
Bid Schedule (bid)	20 %	20 %	0 %
Bid Technical (bid)	19 %	15 %	+4 %
Technical Ability (bid)	14 %	15 %	-1 %
Experience Record (bidder)	11 %	15 %	-4 %
BIM (bid and bidder)	12 %	5 %	+7 %
Expected Performance	14 %	-	+14 %
Total	100 %	100 %	0 %

While a direct comparison is challenging due to variations in criteria across different areas of concern and the introduction of a new area ("expected performance"), distinct differences emerge, particularly in the "bid financial" category (-20%).

In this case, the MCDA analysis triggered a shift, elevating the importance of "BIM" (+7%) and "technical requirements" (+4%), while introducing a notable allocation to "expected performance" (+14%). These changes, along with minor variations observed in the "technical capacity" (-1%) and "experience record" (-4%) categories, contributed to the overall shift of 20%.

These changes are credited to the restructuring process that established a new set of criteria grounded in a value-focused thinking, but also due to the systematic weighting procedure that considered the intrinsic performance levels of the criteria.

5.3.3. Applying the evaluation model

Performance profiles

The impact profiles of the tenders (A, B, C, D) were organized in a performance table, considering the predefined performance measures (A1 to A6). **Figure 6** shows an excerpt from this table, obtained from the MACBETH software system.

Table of performances

Options	OverallPrice	FinancialSchedule	OverallTime	NetDiagram	FinCompatibility	EquipMan	TechnicalReport	QuaPlan	EnvPlan	SafPlan
A	A2	A4	A1	A4	A4	A4	A5	A5	A5	A5
B	A6	A6	A5	A6	A6	A6	A2	A2	A2	A2
C	A5	A5	A4	A5	A5	A5	A4	A4	A4	A4
D	A1	A3	A6	A3	A3	A3	A3	A3	A3	A3

Figure 6. Table of performances (excerpt).

Ranking options

The overall ranking was established through the additive value model by combining the scores of each tender with the assigned weights for all the 27 criteria. **Figure 7** illustrates the results, outlining a distinct ranking compared to the non-MCDA approach - these results are discussed in section 5.4.

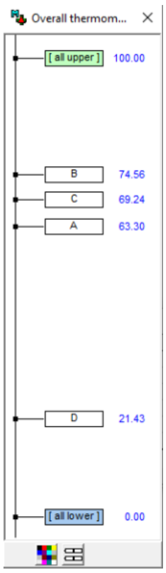

Figure 7. Overall thermometer.

For a comprehensive understanding of the models' outcomes, an analysis was conducted to determine how each criterion contributes to the overall score of the tenders. **Figure 8** illustrates the profile of tender B, demonstrating that criteria associated with financial aspects, schedule, and expected performance (highlighted in red rectangles) held the most substantial significance.

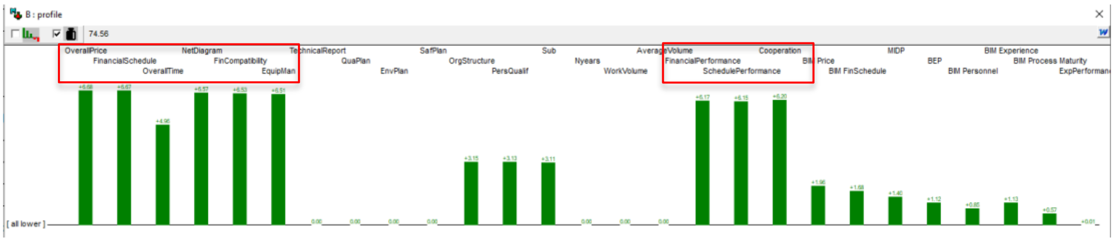

Figure 8. Tender B profile (weighted scores).

5.3.4. Testing the requisiteness of the model

Sensitivity analysis

To explore the impact of adjusting the relative weight of key criteria on the overall scores and global ranking, a weight analysis was conducted.

Figure 9 illustrates the outcomes for the criteria "overall price" (5.01% weight) and "overall time" (4.96% weight). In both scenarios, it is evident that tender B is prevalent until 63.4%, a weight value that is practically unlikely to achieve. This reinforces the consistency of the model at the current weight values and reaffirms tender B as the optimal choice.

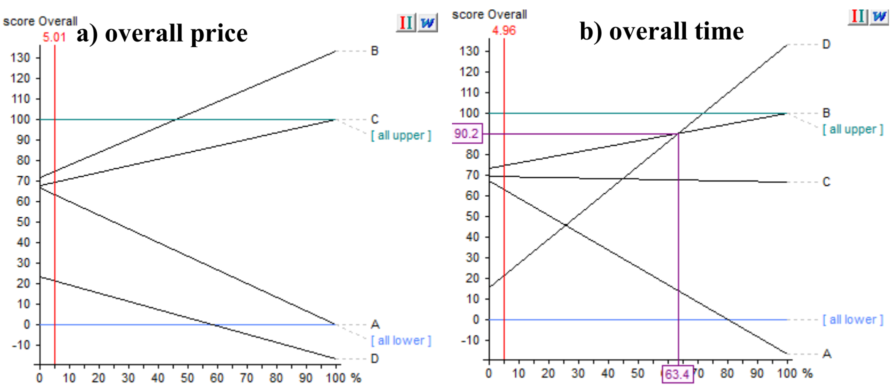

Figure 9. Sensitivity analysis on the weights: a) overall price and b) overall time.

A sensitivity test was conducted by removing the BIM criteria from the problem structure to evaluate its impact on the outcomes. The results, represented in **Figure 10**, compared to **Figure 7**, indicate minimal alteration in overall scores and the global ranking. Notably, tender B remains consistently the top choice across various weightings.

Actually, according to this paper's author experience, despite its value in enhancing construction project performance, the BIM methodology often does not hold pivotal importance in procurement decisions.

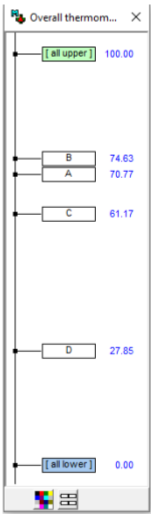

Figure 10. Overall thermometer (without BIM).

Robustness analysis

The model's robustness was assessed by simultaneously varying multiple weights while maintaining their predefined order of importance, aiming to gauge the consistency of the model across different weight combinations.

When solely considering ordinal information (options ranked by order of magnitude), conclusions on the tenders' ranking couldn't be drawn due to potential inconsistencies arising from not considering differences in attractiveness. However, by appropriately considering cardinal information (interval scales), which considers differences in attractiveness, and utilizing the additive model (additive dominance), the results were clear, as demonstrated in **Figure 11**: B dominates C, A, and D; C dominates A and D; and A dominates D. In conclusion, the analysis reaffirmed tender B as the optimal choice.

Robustness analysis

	A	B	C	D	[all upper]	[all lower]
A	=			+		+
B	+	=	+	+		Δ
C	+		=	+		Δ
D				=		+
[all upper]	Δ	+	+	+	=	Δ
[all lower]						=

(+=situation of dominance as a result of the additive model; Δ=situation of dominance, regardless of the additive model)

*a 10% margin of error was applied to both criteria and weights.

Figure 11. Robustness analysis considering cardinal information.*

5.4 Formulating recommendations

In this case study, the tender evaluation was restructured, considering the MCDA framework proposed in section 4, supported by MACBETH. This reassessment considered the specific requirements of public procurement and the integration of BIM, both in structuring the problem and constructing the evaluation model.

The MCDA analysis yielded different results compared to the conventional approach (without MCDA), resulting in a shift of the leading tender from C to B. As illustrated in **Figure 12**, the score difference between proposals B and C mainly originates from criteria associated with financial aspects, schedule, and expected performance (highlighted in red rectangles). These criteria align with those carrying more weight in the calculation of the overall score for tender B, as depicted in **Figure 8**.

Figure 12. Difference profile B-C (weighted scores).

The MCDA, compared to traditional methods, stands out in structuring the decision problem, which significantly impacts the construction of the evaluation model. This is due to its value-focused approach that integrates CA preferences, contributing to the reliability of the model.

The MCDA analysis revealed that the impact of BIM criteria on the winning bid is limited, as even without them, tender B remains the optimal choice.

An important point to highlight pertains to the impact of adding or removing tenders in the results obtained through an MCDA analysis supported by MACBETH. By considering performance references, which hold intrinsic value and enable the establishment of scales for independently assessing the attractiveness of each tender, it can be concluded that the results remain unchanged when introducing or removing tenders in the evaluation process. This is particularly noteworthy, as it often happens, for instance, when proposals lose their attractiveness and are consequently removed from the process, new tenderers are added, or variant proposals are introduced.

This consistency in results stands out as a significant advantage of the proposed methodology, aligning seamlessly with the principles of proportionality and fairness within the realm of public (and private) construction procurement, given the evaluation of tender proposals based on their intrinsic value, irrespective of other tender features.

6. CONCLUSIONS

6.1 Main findings

When it comes to awarding construction works contracts, the bid price holds undeniable importance; however, relying solely on this criterion can be very risky for project success. The selected contractor shall possess specific capabilities that align with project requirements, the priorities of the contracting authorities, and the growing demands of digitalization, particularly in the context of the BIM methodology. In recent years, there has been an increasing body of literature emphasizing the limitations of traditional evaluation methods which focus predominantly on bid price. This underscores the need for a more comprehensive approach to evaluation that considers various qualitative and quantitative criteria.

A detailed review of the literature reveals a significant research gap in the application of MCDA frameworks integrated with BIM for construction tender evaluations, particularly in terms of developing and applying standardized evaluation criteria tailored to BIM-specific needs - the evaluation of construction tenders should encompass all relevant criteria. Furthermore, the evaluation process shall adhere to the principles of non-discrimination, proportionality, and transparency, which are fundamental pillars of public procurement, as outlined by the European Directive 2014/24/EU - these principles form the foundation for the present study.

In this context, a BIM-integrated MCDA approach supported by MACBETH is proposed. It is applicable to both the public and private domains, serving as a reference guide for contracting authorities to assess and select the best tender for BIM-based construction works contracts. The proposed methodology is detailed in section 4, and its application is demonstrated in section 5 through a real-world case study.

The proposed MCDA tender evaluation framework meets the unique assessment needs of BIM-based construction projects, filling the gap identified in ISO19650 standards related to BIM-specific evaluation criteria, and aligns with the public procurement requirements. In addition to allowing the publication of the complete evaluation model, including criteria, weights, and scoring rules, in the tender document as part of the invitation to tender, the framework also permits evaluation based on the intrinsic value of tender proposals, irrespective of other tender features. This is in line not only with the European Directive 2014/24/EU but also with more demanding regulations such as the Portuguese Code of Public Contracts.

To support the structuring of the decision problem, a BIM-integrated framework is presented, featuring both screening and evaluation criteria along with their respective performance references ("neutral" and "good"), as detailed in **Appendices 1 and 2**. This framework, developed through a value-focused approach and informed by insights from construction experts, exhibits potential applicability across diverse construction tender evaluation processes in both public and private domains. It is designed to be adaptable on a case-by-case basis, as demonstrated in **Appendix 3**. This appendix showcases an adaptation of the general framework presented in **Appendices 1 and 2** to the specific context of the case study outlined in this paper.

The utilization of MACBETH to support the implementation of MCDA within the framework of an additive model for preference aggregation stands out for its user-friendly approach, resonating with decision-makers, as it allows accommodating their preference for qualitative input while acknowledging the importance of quantitative data. This approach proves particularly useful within the context of the construction industry, characterized by complex and multifactorial decision-making processes, where variables are not always easy to objectively assess and quantify at first.

However, the success of the proposed MCDA framework requires technical proficiency to ensure a thorough application, maintaining process integrity and aiding decision-makers in accurately selecting the ideal contractor for each unique contract. For instance, it is imperative to steer clear of common evaluation pitfalls, such as blindly assigning weights to criteria without considering their impact levels.

The case study validated the practicality of the proposed frameworks under public procurement procedures, highlighting the potential benefits of a value-based approach in tender evaluations for construction works and demonstrating that a more robust and objective assessment process can lead to different outcomes - such as selecting tender B over tender C - compared to traditional methods, which may overlook the multifaceted nature of modern construction projects.

Notably, the influence of BIM criteria was deemed irrelevant, as the overall ranking would remain unchanged even if they were excluded. This finding underscores the importance of carefully considering the role of BIM in tender evaluations and adopting a balanced approach that effectively integrates both BIM and non-BIM factors. It also reflects BIM's relative importance in the construction industry, where, despite being a methodology that facilitates efficiency gains, it is not strictly necessary for project completion and does not play a decisive role in awarding construction contracts.

6.2 Limitations and future research

The study acknowledges several noteworthy limitations, which constitute opportunities for future research.

Firstly, one significant constraint arises from the nature of decision-making, even within structured methodologies like MCDA. Despite its framework, decision-makers' discretionary power introduces the potential for drawbacks when intermittently relying on intuition and subjective judgments. This reliance may lead to decisions influenced by motivational and cognitive biases, resulting in deviations from authentic values and preferences.

Another limitation is related to the potential impact of changes within the decision-making body or adjustments in the timing of decision processes. Such changes can result in divergent outcomes due to disparities in judgments and problem structuring. While these potential inconsistencies are acknowledged, within the constraints of the available information at a specific moment, MCDA continues to stand as a valuable tool for informed decision-making.

Furthermore, this study addresses project risk and uncertainty by proposing criteria linked to expected performance instead of past performance, considering regulatory constraints related to non-discrimination specified by the European Directive 2014/24/EU. This approach aims to reduce costs when projects perform well, contrasting with those solely involving penalties outlined in contract documents. To achieve this goal, attaining a balanced criterion weighting and appropriate rewards is critical (Tavares et al, 2013).

Importantly, the application of the proposed evaluation framework presupposes the adequate incorporation of BIM requirements into the tendering documents for construction works, in coherence with the BIM-specific evaluation criteria to be adopted. This gap in the literature represents a foundation for future studies to develop a comprehensive BIM-integrated tendering methodology, which should combine traditional processes with recognized BIM standards and public procurement regulations, particularly the ISO 19650 standards and the European Directive 2014/24/EU. Such a methodology would be applicable to both the public and private sectors, and could serve as a reference guide for contracting authorities.

Lastly, this study specifically explores the BIM-based tender evaluation for the execution phase of construction projects. However, the successful implementation of BIM depends on a comprehensive assessment that incorporates the necessary specifications throughout all stages of project development. Particularly, the design phase, which precedes the construction works, is critical for ensuring BIM's effectiveness during execution and extending into the operational phase.

APPENDIXES

-**Appendix 1**: BIM-integrated framework featuring both screening and evaluation criteria and performance references (“neutral” and “good”).

-**Appendix 2**: BIM-integrated framework: evaluation criteria value tree.

-**Appendix 3**: Case study BIM-integrated framework: evaluation criteria value tree.

REFERENCES

Albano, G., Berardino, A. (2011). Relational procurement contracts: a simple model of reputation mechanism. CEIS Working Paper, 209.

Ariffin, H., Raslim, F., Cun, K., Mustaffa, N. (2017). Factors Concerning Procurement Selection in Building Information Modelling (BIM) Projects. 5th International Conference on Research and Innovation in Information Systems, 1-6.

Bana e Costa, C., Corrêa, E., De Corte, J., Vansnick, J. (2002). Facilitating bid evaluation in public call for tenders: a socio-technical approach. Omega, 30(3), 227-242.

Bana e Costa, C., De Corte, J., Vansnick, J. (2012). MACBETH. International Journal of Information Technology & Decision Making, 11(2), 359-387.

Bana e Costa, C., Vansnick, J. (1994). MACBETH: an interactive path towards the construction of cardinal value functions. International Transactions in Operational Research, 1, 489–500.

Bana e Costa, C., Correa, E., Ferreira, J. (2000). Metodologia Multicritério de Apoio à Avaliação de Propostas em Concurso Públicos. Casos de Aplicação da Investigação Operacional, Mcgraw-Hill, 337-363.

Belton, V., Stewart, T. (2003). Multiple Criteria Decision Analysis: An Integrated Approach. Kluwer Academic Publishers Group, Massachusetts.

CEN. (2018a). Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling - Part 1: Concepts and principles. EN ISO 19650-1, European Committee for Standardization, Brussels, Belgium.

CEN. (2018b). Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling - Part 2: Delivery phase of the assets. EN ISO 19650-2, European Committee for Standardization, Brussels, Belgium.

Decree-Law 18/2008 (2008). Aprova o Código dos Contratos Públicos (CCP), que estabelece a disciplina aplicável à contratação pública e o regime substantivo dos contratos públicos que revistam a natureza de contrato administrativo. Diário da República Portuguesa, Portugal.

Directive 2014/24/EC (2014). Directive 2014/24/EU of the European Parliament and of the Council of 26 February 2014 on public procurement and repealing Directive 2004/18/EC. Official Journal of the European Commission, Brussels, Belgium.

Ellis, R., Herbsman, Z. (1991). Cost-time bidding concept: an innovative approach. Transportation Research Record, Washington D.C., 89-94.

Fregonara, E., Ferrando, D., Tulliani, J. (2022). Sustainable Public Procurement in the Building Construction Sector. Sustainability, 14, 11616.

Garcia, A., Dorta, N., Aranda, J. (2021). BIM Requirements in the Spanish Public Tender - Analysis of Adoption in Construction Contracts. Buildings, 11(12), 594.

Goodwin, P., Wright, G. (1997). Decision Analysis for Management Judgement. John Wiley & Sons, Chichester.

Hatush, Z., Skitmore, M. (1997). Assessment and evaluation of contractor data against client goals using PERT approach. Construction Management and Economics, 15(4), 327-340.

Hatush, Z., Skitmore, M. (1998). Contractor selection using multicriteria utility theory: An additive model. Building and Environment, 33(2-3), 105-115.

Keeney, R. (1992). Value-Focused Thinking: a Path to Creative Decisionmaking. Harvard University Press, Cambridge.

Keeney, R., Raiffa, H. (1976). Decisions with Multiple Objectives: Preferences and Value Tradeoffs. John Wiley & Sons.

Khoso, A., Yusof, A., Chai, C., Laghari, M. (2021). Robust contractor evaluation criteria classification for modern technology public construction projects. Journal of Public Procurement, 21(1), 53-74.

Lehtonen, J., Virtanen, K. (2022), Choosing the most economically advantageous tender using a multi-criteria decision analysis approach. Journal of Public Procurement, 22(2), 164-179.

Macek, D. (2023). "A Tool for Evaluating Public Procurement in the Context of Life Cycle Costs." International Journal of Economic Sciences, 12(1), 133-143.

Mahamadu, A., Mahdjoubi, L., Booth, C. (2017). Critical BIM qualification criteria for construction pre-qualification and selection. Architectural Engineering and Design Management, 13(5), 326-343.

Mahamadu, A., Manu, P., Mahdjoubi, L., Booth, C., Aigbavboa, C., & Abanda, F. H. (2020). "The importance of BIM capability assessment: An evaluation of post-selection performance of organisations on construction projects." Engineering, Construction and Architectural Management, 27(1), 24-48.

Mahdi, I. M., Riley, M., Fereig, S. M., Alex, A. P. (2002). "A multi-criteria approach to contractor selection." Engineering, Construction and Architectural Management, 9(1), 29-37.

Marović, I., Perić, M., Hanak, T. (2021). A multi-criteria decision support concept for selecting the optimal contractor. Applied Sciences, 11(4), 1660.

Mateus, R., Ferreira, J., Carreira, J. (2010). "Full disclosure of tender evaluation models: Background and application in Portuguese public procurement." Journal of Purchasing & Supply Management, 16, 206-215.

Matos, B., Cruz, C., Branco, F. (2024). "Digitalization and Procurement in Construction Projects: an integrated BIM-based approach." Journal of Information Technology in Construction, 29, 400-423.

Park, K., Ock, J. (2022), Structuring a BIM Service Scoping, Tendering, Executing, and Wrapping-Up (STEW) Guide for Public Owners. Applied Sciences, 12, 3275.

Popov, V., Medineckienė, M., Grigorjeva, T., Zabulėnas, A. (2021). Building information modelling: Procurement procedure. Business, Management and Economics Engineering, 19(1), 180-197.

Russo Ermolli, S., De Toro, P. (2017). Process innovations for the digitalization of public procurement: synergies between BIM and multi-criteria analysis. Journal of Technology for Architecture and Environment, 13, 313-321.

Skitmore, R., Ng, S. (2001). Contractor selection criteria: a cost–benefit analysis. IEEE Transactions on Engineering Management, 48(1), 96-106.

Tavares, L., Costa, A. (2013). Advanced multicriteria models to promote quality and reputation in public construction e-marketplaces. Automation in Construction, 30, 205-215.

Tavares, L., Arruda, P. (2022a). A multicriteria model to select candidates for public contracting using the OPTIONCARDS method. Automation in Construction, 136.

Tavares, L., Arruda, P. (2022b). A new approach to public contracting of technological services. Innovation: The European Journal of Social Science Research

Topcu, Y. (2004). A decision model proposal for construction contractor selection in Turkey. Building and Environment, 39(4), 469-481.

Wang, M., Luo, Y. (2009). "On rank reversal in decision analysis." Mathematical and Computer Modelling, 49(5-6), 1221-1229.

Wang, Y., Gosling, J., Naim, M. (2019). Assessing supplier capabilities to exploit building information modelling. Construction Innovation, 19(3), 491-510.

Winterfeldt, D., Edwards, W. (1986). Decision Analysis and Behavioural Research. Cambridge, Cambridge University Press.

Appendix 1. BIM-integrated framework featuring both screening and evaluation criteria and performance references ("neutral" and "good").

0	Screening Criteria	Context
0.1	**Completeness of documentation (bid)**	
0.1.1	Shortage contract offer	Is there any shortage in the contract offer, such as documents or drawings, according to the general bid conditions?
0.1.2	Financial capability	Has the contractor presented to the owner enough proof that he has the financial capability to execute the project?
0.1.3	Technical capability	Has the contractor submitted sufficient documents to show his technical capability in accomplishing the project?
0.1.4	Required bond	Has the contractor submitted the required bond(s)?
0.2	**Classification (bidder)**	
0.2.1	License	Does the contractor's license meet the required degree by the project, according to the law?
0.2.2	Capital	Does the contractor's capital cover the actual project cost?
0.3	**Financial Soundness (bidder)**	
0.3.1	Financial Statements	Do the financial statements (last 3 years) meet the required levels?
0.3.2	Credit level and Payment record	Do the contractor's credit level and payments records to his creditors (e.g. suppliers, subcontractors) meet the required levels?
0.4	**Project constraints (bid)**	
0.4.1	Cost	Does the proposed global price meet the base price (price limit predefined by the owner)?
0.4.2	Time	Does the proposed global deadline meet the base deadline (time limit predefined by the owner)?

1	**Bid Financial (bid)** - financial evaluation of the bid	**Neutral level**	**Good level**
1.1	**Overall price**	The contractor's bid is competitive, without being significantly higher or lower compared to other bids. The updated global value of the proposal reflects a reasonable and competitive price considering the base price, project requirements and market conditions.	The contractor's bid is competitive, being significantly lower compared to other bids. The updated global value of the proposal demonstrates a highly competitive price, indicating the contractor's ability to offer cost-effective solutions without compromising the project's quality or scope.
1.2	**Price change** (due to constraints)	The competitor identifies and reports certain constraints, which have resulted in adjustments to the base price presented by the owner. These constraints, whether related to project-specific conditions, unforeseen circumstances, or other factors, are acknowledged and reflected in the revised price, indicating a moderate level of flexibility and adaptability in addressing these constraints. The competitor provides a clear explanation of the factors that necessitated the price change.	The competitor demonstrates a high level of transparency and accuracy in identifying and reporting constraints that resulted in a change to the base price presented by the owner. They provide detailed justifications and documentation for the adjustments, ensuring that the revised price accurately reflects the impact of the constraints established or reported by them. The competitor's ability to identify and account for these factors in their pricing demonstrates a strong understanding of the project's requirements and an effective approach to managing financial considerations.
1.3	**Unbalanced bid**	The contractor's bid may show minor deviations or imbalances in the distribution of prices across different project elements or tasks. While there may be some variations, they do not significantly impact the overall project cost or raise concerns about fairness or equity.	The contractor's bid is well-balanced, with appropriate and proportional pricing across all project elements or tasks. There are no significant deviations or imbalances that could potentially impact the project's cost or compromise the fairness of the bid evaluation process.
1.4	**Calculation mistake**	The contractor's bid may contain minor calculation mistakes that do not significantly impact the overall cost or the accuracy of the bid. These errors can be rectified or clarified through communication and verification.	The contractor's bid is free from any calculation mistakes. The pricing is accurately calculated, reflecting attention to detail and a high level of precision in the bid preparation process.
1.5	**Financial reservation**	The contractor may have included minor financial reservations or qualifications in their bid, indicating certain limitations or conditions related to the financial aspects of the project. These reservations are not significant enough to raise concerns about the contractor's ability to meet the project's financial requirements.	The contractor has not included any financial reservations in their bid. They demonstrate a strong commitment to fulfilling the project's financial obligations without any conditions or limitations.
1.6	**Financial schedule**	The contractor's financial schedule is generally aligned with the project's timeline and milestones. However, there may be some minor deviations or discrepancies between the schedule and the project's overall timeline. The schedule provides a basic outline of the anticipated payment milestones, but it lacks specific details or contingencies for potential delays or changes in the project's progress.	The contractor's financial schedule is well-aligned with the project's timeline and milestones. It demonstrates a clear understanding of the project's financial requirements and incorporates specific details and contingencies to accommodate potential delays or changes in the project's progress. The schedule is comprehensive and provides a solid foundation for effective financial management throughout the project's planning and execution phases.

2	Bid Schedule (bid)	Neutral level	Good level
2.1	**Overall time**	The competitor's proposed overall schedule or total duration is expected to be reasonably competitive, without significant deviations from the deadline presented in the owner's base proposal. The competitor's bid reflects a competitive approach to project scheduling, ensuring a timely completion of the work.	The competitor's proposed overall schedule or total duration showcases good efficiency and acceleration compared to other bids. The updated global value of the proposal demonstrates the competitor's ability to optimize time and resources. The proposed schedule reflects a high level of expertise in planning and executing the work, allowing for timely completion without compromising the project's quality or scope. The competitor's commitment to delivering the project within an accelerated timeline indicates their proficiency in offering time-efficient solutions while ensuring adherence to project requirements and standards.
2.2	**Time change** (schedule change due to constraints)	The competitor has reported certain constraints or conditions that have resulted in a minor adjustment to the final delivery deadline of the work as established by the owner. These constraints, although they may have caused some schedule modifications, are considered reasonable and within acceptable limits. The competitor has demonstrated their ability to address and adapt to these constraints while still ensuring the project can be completed within a reasonable timeframe. The adjustments to the schedule are manageable and should not significantly impact the overall project timeline.	The competitor has effectively managed and mitigated any constraints or conditions that could potentially affect the final delivery deadline of the work as established by the owner. Through proactive planning and effective project management, the competitor has demonstrated their ability to overcome challenges and minimize schedule changes. Their approach and solutions have allowed for efficient execution and timely completion of the project. The competitor's commitment to delivering the work within the agreed-upon schedule showcases their strong project management skills and ability to meet project milestones without compromising quality or scope.
2.3	**Work program**		
2.3.1	**Network diagram** (Number and Level of Disaggregation of Activities, Critical Path, and Slack)	The competitor's work program demonstrates a moderate understanding of the activities that need to be developed, their interactions, and sequential relationships. They provide a reasonable level of detail, but there may be occasional gaps or areas for further clarity.	The competitor's work program showcases a strong understanding of the activities that need to be developed, their interactions, and sequential relationships. They provide a comprehensive level of detail, ensuring a clear understanding of the project's critical path and slack.
2.3.2	**Financial compatibility** (Compatibility of the Work Program and Financial Plan)	The competitor's work program and financial plan show a moderate level of compatibility. There may be some discrepancies or areas where adjustments are needed to align the financial plan with the work program.	The competitor's work program and financial plan exhibit a high level of compatibility. They have accurately calculated the financial plan based on the monthly production on-site and unit prices of materials and labor, ensuring a harmonious alignment between the two.
2.4	**Equipment and manpower**	The competitor's equipment and manpower schedule demonstrates a moderate level of planning and organization regarding the allocation and utilization of both equipment and manpower resources. The schedule provides a reasonable level of detail, but there may be some gaps or areas for improvement in terms of coordinating and optimizing the utilization of equipment and manpower together.	The competitor's equipment and manpower schedule showcases a high level of planning and organization regarding the allocation and utilization of both equipment and manpower resources. The schedule provides a comprehensive and detailed plan that effectively coordinates and optimizes the utilization of equipment and manpower together. It ensures efficient use of resources and promotes productivity throughout the project.

3	Bid Technical (bid)	Neutral level	Good level
3.1	**Technical report** (descriptive and justifying report)	The competitor's descriptive and justifying report demonstrates a moderate understanding of the patented pieces in the competition and their intended execution of the work. They provide some details on human resources and equipment allocation, but there may be areas that require further elaboration or clarity.	The competitor's descriptive and justifying report showcases a comprehensive understanding of the patented pieces in the competition and their proposed execution of the work. They provide clear and detailed information on human resources and equipment allocation, ensuring a strong understanding of their approach.
3.2	**Quality plan**	The competitor provides a quality plan that demonstrates a moderate capacity to ensure the quality of the work and compliance with legislation. They outline some measures and processes to maintain quality standards, but there may be occasional gaps or areas for improvement.	The competitor presents a comprehensive quality plan that showcases their strong capacity to guarantee the quality of the work and compliance with legislation. They have well-defined measures and processes in place to ensure adherence to quality standards.
3.3	**Environmental plan** (environmental assessment system)	The competitor demonstrates a moderate capacity to guarantee the control of the environmental assessment system in the work and compliance with legislation. They outline some measures and procedures to address environmental concerns, but there may be room for improvement or further elaboration.	The competitor exhibits a comprehensive capacity to guarantee the control of the environmental assessment system in the work and compliance with legislation. They have well-defined measures and procedures in place to address environmental requirements and ensure compliance.
3.4	**Safety plan**	The competitor's safety plan showcases a moderate capacity to ensure the control of safety conditions in the work and compliance with legislation. They outline some safety measures and protocols, but there may be areas for improvement or further emphasis on safety practices.	The competitor's safety plan demonstrates a high capacity to ensure the control of safety conditions in the work and compliance with legislation. They have well-defined safety measures and protocols in place, showcasing a commitment to maintaining a safe working environment.

4	Technical Ability (bid)	Neutral level	Good level
4.1	**Organisational Structure**	The organizational structure is generally well-defined and functional, supporting the project's objectives and requirements. Roles and responsibilities are clearly defined, but there may be some areas for improvement in terms of communication, coordination, or efficiency. The structure adequately supports project execution, but there may be minor inefficiencies or overlapping responsibilities.	The organizational structure is well-designed, efficient, and effectively supports the project's objectives and requirements. Roles and responsibilities are clearly defined and properly aligned, promoting effective communication, coordination, and decision-making. The structure optimizes project execution, ensuring streamlined workflows and minimizing inefficiencies or conflicts.
4.2	**Personnel qualification**	The technical personnel demonstrate a satisfactory level of qualification and possess the necessary skills and expertise to fulfill their roles and responsibilities in the project. They meet the minimum requirements and standards expected for their respective positions, but there may be some areas for improvement or additional training needs identified.	The technical personnel exhibit a high level of qualification and possess extensive knowledge, experience, and specialized skills relevant to their roles in the project. They exceed the minimum requirements and standards, demonstrating exceptional competence and expertise. There are no significant gaps or deficiencies in their qualifications or capabilities.
4.3	**National manpower**	The contractor demonstrates a moderate level of recruitment of national manpower within their technical or administrative staff. While efforts are made to hire local talent, there may be a mix of national and international staff in these roles. The contractor recognizes the importance of utilizing local expertise but may still rely on international staff for certain specialized positions or expertise that is not readily available locally. The overall recruitment strategy aims for a balanced representation of national manpower within the technical and administrative staff.	The contractor actively recruits and prioritizes national manpower within their technical or administrative staff. The majority of these positions are filled by local talent, demonstrating a strong commitment to supporting the local workforce. The contractor invests in the development and training of national staff to build their capacity and enhance their expertise. The recruitment strategy focuses on maximizing the utilization of qualified local professionals, minimizing the reliance on international staff for technical and administrative roles.
4.4	**Subcontractors**	The contractor engages subcontractors for specific portions of the work, including a variety of tasks and responsibilities. While the subcontractors are generally qualified for their assigned work, there may be occasional instances where subcontractors are found to be unqualified either financially or technically. This could be due to their inadequate financial resources or a lack of technical expertise in certain areas. The contractor makes efforts to mitigate such instances but may encounter some challenges in ensuring the complete qualification of all subcontractors.	The contractor carefully selects subcontractors based on their qualifications, both financially and technically, for the specific tasks and responsibilities. The type of work subcontracted is well-defined and aligns with the subcontractors' areas of expertise. The subcontractors demonstrate strong financial stability and possess the necessary technical skills and experience to fulfill their roles effectively. The contractor ensures that all subcontractors meet the required qualifications and verifies their financial and technical capabilities before engaging them.
4.5	**Construction methods**	The contractor demonstrates a moderate level of keeping up to date in their field by adapting recent technical methods in executing the project. While there is an awareness of new technologies and techniques, the contractor may not fully embrace or implement them in all aspects of the project. There may be some areas where traditional or conventional methods are still utilized. The contractor makes efforts to stay informed about recent technical advancements, but there may be room for improvement in the consistent adoption of these methods.	The contractor proactively keeps up to date in their field and demonstrates a strong commitment to adapting recent technical methods in executing the project. They stay abreast of emerging technologies, industry best practices, and innovative approaches. The contractor consistently implements these recent technical methods throughout the project, leveraging them to improve efficiency, quality, and overall project performance. Their focus on staying current ensures that the project benefits from the latest advancements in their field.
4.6	**Technical reservation**	The contractor has included some technical reservations in their bid, indicating certain concerns or limitations related to the project's technical aspects. These reservations may pertain to specific technical requirements, materials, equipment, or methods. The contractor acknowledges potential challenges or uncertainties and seeks clarification or adjustments to ensure the successful execution of the project. The reservations are communicated to address any potential risks or limitations.	The contractor's bid does not include any technical reservations, indicating a high level of confidence in their technical capabilities to execute the project as per the specified requirements. The contractor thoroughly assesses the project's technical aspects and provides a comprehensive and reliable bid that accounts for all necessary technical considerations. Their bid reflects a clear understanding of the project requirements, technical feasibility, and the ability to meet the desired outcomes without reservations.
4.7	**Joint venture**	In a joint venture, there may be some moderate doubts regarding the contractor's technical or financial capability, or their ability to fulfill their commitments toward the other contractors and the project representative. While there might be some concerns, they are not significant enough to raise serious doubts about the contractor's overall performance.	In a joint venture, there are no doubts regarding the contractor's technical or financial capability, or their ability to keep their commitments toward the other contractors and the project representative. They have a proven track record of successful joint ventures and demonstrate a high level of trustworthiness, reliability, and cooperation.

5	Alternative Offer (bid)	Neutral level	Good level
5.1	**Cheaper bid_no advance payment**	The contractor has not offered a replacement method that significantly reduces costs while maintaining the same technical quality as specified in the project specifications. Although some minor cost-saving alternatives may have been proposed, they do not present a significant advantage in terms of economical execution.	The contractor has suggested a replacement method that offers the same technical quality as specified but at a significantly lower cost. This alternative method provides an economical way of executing the project without compromising the required quality standards. The contractor's ability to identify cost-effective solutions demonstrates their innovative thinking and commitment to optimizing project resources.
5.2	**Cheaper bid_with advance payment**	The contractor has not offered a significant price deduction in exchange for a substantial advance payment from the owner. Although some minor adjustments in the bid price may have been proposed, they do not present a significant advantage in terms of financial savings.	The contractor has offered a considerable price reduction if the owner is willing to make a substantial advance payment. This incentive demonstrates the contractor's flexibility and willingness to accommodate the owner's financial preferences. The contractor's ability to provide a cheaper bid with the option of an advance payment showcases their commitment to finding mutually beneficial solutions.
5.3	**Shorter period_with payment**	The contractor has suggested a slightly shorter project duration, even though the owner's cash flow can support the original timeline. The proposed acceleration in project execution is considered reasonable, but it does not significantly reduce the overall duration.	The contractor has proposed a substantially shorter project duration, considering that the owner's cash flow can support the accelerated timeline. This suggestion showcases the contractor's efficiency and ability to expedite project execution without compromising quality. The contractor's commitment to delivering the project within a shorter period, considering the available resources, demonstrates their dedication to meeting the project objectives in a timely manner.
5.4	**Shorter period_no payment**	The contractor has suggested a slightly shorter project duration, even though the owner's cash flow may not be able to support the accelerated timeline. The proposed acceleration in project execution is considered reasonable, but it does not significantly reduce the overall duration.	The contractor has proposed a substantially shorter project duration, despite the potential limitations in the owner's cash flow. This suggestion demonstrates the contractor's commitment to delivering the project in a timely manner, even if it means overcoming financial challenges. The contractor's ability to propose an accelerated timeline while considering the owner's constraints showcases their proactive approach and dedication to meeting project milestones.
5.5	**Better quality**	The contractor has not submitted any alternative offers that significantly enhance the quality of the project while still meeting the original objectives. Although the submitted offers may provide some minor improvements, they are considered to be on par with the specified requirements and do not present a substantial advantage in terms of quality.	The contractor has proposed alternative offers that not only meet the specified objectives but also offer significant improvements in terms of quality. These alternative offers are considered to be financially and technically advantageous, providing added value to the project. The contractor's ability to suggest alternative solutions that enhance the quality while remaining within the project's financial framework demonstrates their expertise and commitment to delivering an excellent outcome.

6	Project Location (bidder)	Neutral level	Good level
6.1	**Site proximity**	The contractor's head office, branches, or technical staff are moderately located near the site. There may be a reasonable level of proximity, but it may not be the most optimal location in terms of travel time and logistical considerations.	The contractor's head office, branches, or technical staff are well-located near the site, ensuring convenient access and reduced travel time. This proximity enables efficient communication, coordination, and timely decision-making throughout the project.
6.2	**Site familiarity**	The contractor demonstrates a moderate level of familiarity with the geographical, social, economic, and political aspects of the site. They have experience working on projects with similar geographical conditions in the last years, indicating a reasonable understanding of the challenges and requirements associated with such sites. However, there may be some uncertainties or gaps in their knowledge of the specific site's conditions and how they might impact the project.	The contractor exhibits a high level of familiarity with the geographical, social, economic, and political aspects of the site. They have successfully completed similar projects in locations with comparable geographical conditions in the last years. Additionally, they have proven experience in managing and mitigating the impact of similar weather conditions on their previous projects. This indicates a strong understanding of the site's challenges and their ability to adapt and deliver successful outcomes.

7	Experience Record (bidder)	Neutral level	Good level
7.1	**Number of years** (working in similar projects and in construction generally)	The contractor has a moderate number of years of experience working in similar projects and in the construction industry. They possess a satisfactory level of familiarity and understanding in the field.	The contractor has a high number of years of experience working in similar projects and in the construction industry. They have extensive knowledge and expertise, demonstrating a high level of competence and understanding in the field.
7.2	**Total work volume** (in similar projects and in construction generally)	The contractor has handled a moderate amount of work volume in similar projects and within the construction industry as a whole. They have successfully completed projects of average scale and complexity.	The contractor has handled a high amount of work volume in similar projects and in the construction industry. They have a proven track record of successfully managing and delivering projects of significant scale and complexity.
7.3	**Average work volume** (on similar projects and in construction generally)	The contractor has a moderate work volume on similar projects and in the construction industry. Their workload aligns with industry standards.	The contractor has a high work volume on similar projects and in the construction industry. They consistently manage and handle a higher workload than the industry average, demonstrating efficiency and capacity to handle multiple projects.
7.4	**Different contract types** (working with different contract types, last 3 years, lump-sum contract and unit-price contract)	The contractor has moderate experience working with different contract types, including both lump-sum and unit-price contracts, in the last three years. They have successfully executed projects using various contract types.	The contractor has high experience working with different contract types, including both lump-sum and unit-price contracts, in the last three years. They have a proven track record of effectively managing and delivering projects under different contractual arrangements.

8	Expected Performance (bidder)	Neutral level	Good level
8.1	**Financial**	The project's cost performance is expected to be generally in line with the estimated budget, but there may be some minor deviations or unforeseen expenses that impact the overall cost. Trust in cost estimates is moderate, reflecting a reasonable level of confidence in the credibility of the unit prices presented in the proposal. While there may be some variations, the contractor's pricing is generally reliable.	The project is expected to consistently adhere to the estimated budget, demonstrating a high level of cost control and accuracy. Trust in cost estimates is high, and no significant deviations or additional expenses are expected. The contractor's unit prices presented in the proposal are highly credible, providing a strong basis for reliable cost estimation throughout the project. The pricing reflects a thorough understanding of the project requirements and demonstrates industry expertise.
8.2	**Schedule**	The project is expected to progress according to the planned schedule, but there may be occasional delays or minor disruptions that affect the overall timeline. Trust in the contractor's ability to meet deadlines is moderate.	The project is expected to consistently meet or exceeds the planned schedule, demonstrating excellent time management and adherence to deadlines. Trust in the contractor's ability to deliver on time is high, and no significant delays or disruptions are expected.
8.3	**Quality**	The project is expected to deliver the required quality standards but may have occasional minor defects or inconsistencies. Trust in the contractor's ability to consistently deliver high-quality results is moderate.	The project is expected to consistently deliver good quality, meeting the specified standards. No significant defects or inconsistencies ar expected, instilling a high level of trust in the project's ability to deliver quality outcomes.
8.4	**Environmental**	The project is expected to meet the minimum environmental standards and regulations but may have occasional minor shortcomings or areas for improvement. Trust in the contractor's commitment to environmental performance is moderate.	The project is expected to consistently meet the required environmental standards, to demonstrate proactive environmental management, and to implement sustainable practices. Trust in the contractor's commitment to environmental performance is high, and no significant environmental issues or non-compliance are expected.
8.5	**Safety**	The project is expected to maintain basic safety protocols and to meet minimum regulatory requirements, but there may be occasional minor safety incidents or near-misses. Trust in the contractor's safety measures is moderate.	The contractor is expected to demonstrate a good commitment to safety, with a good safety record and a proactive approach to hazard prevention. No significant safety incidents or near-misses are expected, instilling a high level of trust in the project's safety practices
8.6	**Clients relationship**	The project is expected to meet client expectations but may have occasional shortcomings or minor areas for improvement. Client moderate satisfaction is expected, but there may be some concerns or opportunities for enhancement.	The project is expected to consistently meet client expectations, delivering a good service level, and ensuring a good level of client satisfaction. Client high satisfaction is expected, and there are no significant concerns or areas requiring improvement
8.7	**Subcontractors relationship**	The project is expected to maintain basic working relationships with subcontractors, but there may be occasional communication or coordination challenges. Trust in the contractor's ability to collaborate effectively with subcontractors is moderate.	The project is expected to maintain strong and collaborative relationships with subcontractors, ensuring effective communication, coordination, and cooperation. Trust in the contractor's ability to work seamlessly with subcontractors is high, and there are no significant issues in the relationship
8.8	**Suppliers relationship**	The project is expected to maintain standard relationships with suppliers but may encounter occasional challenges in terms of delivery, quality, or communication. Trust in the contractor's ability to effectively engage with suppliers is moderate	The project is expected to maintain good and reliable relationships with suppliers, ensuring timely delivery, high-quality materials, and effective communication. Trust in the contractor's ability to engage with suppliers is high, and there are no significant issues in the relationship
8.9	**Insurers relationship**	The project is expected to maintain standard relationships with insurance companies but may have occasional challenges in terms of claims processing or communication. Trust in the contractor's ability to effectively interact with insurance companies is moderate	The project is expected to maintain good and reliable relationships with insurance companies, ensuring smooth claims processing, effective risk management, and clear communication. Trust in the contractor's ability to engage with insurance companies is high, and there are no significant issues in the relationship
8.10	**Cooperation in problem solving**	The contractor demonstrates a willingness to cooperate and resolve problems but may have occasional challenges in terms of collaboration or finding mutually agreeable solutions. Trust in the contractor's ability to cooperatively solve problems is moderate.	The contractor actively engages in collaborative problem-solving, seeking win-win solutions and demonstrating a proactive and cooperative approach. Trust in the contractor's ability to effectively address and resolve problems is high, and there are no significant issues in cooperation

9	BIM (bid)	Neutral level	Good level
9.1	**BIM Price**	The contractor's proposal presents a global price and price per BIM use that are in line with industry standards and market conditions. The pricing is competitive and reflects the expected costs associated with implementing BIM in the project.	The contractor's proposal demonstrates a highly competitive global price and price per BIM use. The pricing is significantly below market averages, indicating the contractor's ability to offer cost-effective solutions without compromising the quality or scope of the project.
9.2	**BIM Financial Schedule**	The contractor's proposal includes a well-defined financial schedule that aligns with the project's timeline and budget. The payment milestones are reasonable and reflect standard industry practices.	The contractor's proposal presents a financial schedule that demonstrates a high level of financial control and efficiency. The payment milestones are strategically planned, allowing for optimal cash flow management and timely project execution.
9.3	**Master Information Delivery Plan (MIDP)** (deliveries schedule)	The contractor's proposal includes a comprehensive BIM deliveries schedule, also known as the Master Information Delivery Plan (MIDP). The schedule indicates a realistic timeline for the delivery of BIM-related information, ensuring effective collaboration and coordination among project stakeholders.	The contractor's proposal showcases an exceptionally well-structured and detailed BIM deliveries schedule. The MIDP demonstrates the contractor's expertise in BIM coordination and information management, allowing for seamless integration of BIM deliverables throughout the project lifecycle.
9.4	**BIM Execution Plan (BEP)**	The contractor's proposal outlines a BIM process, including a BIM Execution Plan (BEP), which demonstrates the contractor's understanding of BIM methodologies and their ability to implement BIM in the project.	The contractor's proposal presents a comprehensive BIM process, supported by a robust BIM Execution Plan (BEP). The BEP highlights the contractor's extensive experience and expertise in successfully implementing BIM in similar projects, ensuring effective collaboration, information exchange, and project coordination.
9.5	**Collaborative work**	The contractor's proposal emphasizes the importance of collaborative work and highlights their commitment to effective communication and coordination among project stakeholders. The proposal outlines general strategies for facilitating collaborative work but lacks specific details on the platforms and processes to be used.	The contractor's proposal demonstrates a strong emphasis on collaborative work, outlining a clear plan for effective communication, coordination, and information sharing among project stakeholders. The proposal provides specific details on the collaborative platforms, processes, and tools to be utilized, ensuring seamless collaboration throughout the project.
9.6	**BIM Human Resources**	The contractor has a team of human resources dedicated to the BIM process. The qualifications of these individuals in BIM are moderate, with some members having received training or possessing limited experience in BIM implementation. While they have a basic understanding of BIM principles and processes, there may be a need for further development and upskilling to fully leverage the potential of BIM in the project. The competences and capacities of the team are sufficient to handle the basic requirements of the BIM process, but additional expertise and resources may be required for more complex tasks.	The contractor has a highly qualified and experienced team of human resources dedicated to the BIM process. These individuals have received extensive training in BIM implementation and possess a deep understanding of BIM methodologies, tools, and workflows. They have successfully implemented BIM on similar projects in the past, showcasing their expertise in leveraging BIM to improve project outcomes, collaboration, and efficiency. Their qualifications, competences, and capacities in BIM are highly regarded, instilling confidence in their ability to effectively execute the BIM process in the current project. The team has the necessary expertise to handle complex BIM-related tasks and can efficiently manage the requirements of the project.
9.7	**BIM Software and Hardware**	The contractor's BIM software and IT infrastructures are adequately aligned with the requirements of BIM implementation. They have implemented BIM software that is suitable for the intended BIM uses and meets the project's specific needs. Their IT infrastructures are capable of supporting BIM workflows and collaboration, allowing for efficient data management and communication. While the contractor's BIM software and IT infrastructures meet the basic requirements, there may be room for improvement in terms of advanced functionalities and integration capabilities.	The contractor's BIM software and IT infrastructures are well-suited for BIM implementation, providing a robust and efficient platform for project delivery. They have implemented industry-leading BIM software that is fully compatible with the desired BIM uses and meets the project's specific requirements. Their IT infrastructures are robust and scalable, enabling seamless collaboration, data management, and information exchange among project stakeholders. The contractor has demonstrated a proactive approach to adopting advanced functionalities and integrating different software tools, enhancing their capabilities for BIM project delivery.

10	BIM (bidder)	Neutral level	Good level
10.1	**BIM Experience record**	The contractor has a moderate level of experience in developing projects using BIM processes. They have a reasonable number of years of experience in implementing BIM, and they have completed a notable number of projects using BIM methodologies. While they have some experience in executing BIM projects, their track record may not include a significant number of major or complex projects. However, they have demonstrated a level of familiarity and understanding of BIM processes and have successfully implemented them in previous projects of varying scales and complexities.	The contractor has a strong and extensive experience record in developing projects using BIM processes. They have a significant number of years of experience in implementing BIM, and they have successfully completed numerous projects using BIM methodologies, including several major projects. Their experience encompasses a wide range of project types and complexities, demonstrating their ability to adapt BIM to various scenarios. They have a proven track record of implementing BIM effectively, resulting in improved project outcomes, increased collaboration, and enhanced coordination among stakeholders.
10.2	**BIM Process and Maturity**	The contractor has implemented a BIM process within their organization, demonstrating a basic level of organizational maturity in adopting BIM methodologies and practices. They have defined and documented their BIM process, outlining the key steps and workflows for BIM implementation. However, there may be room for improvement in terms of the level of integration and standardization across projects and departments. The contractor shows a moderate level of organizational readiness to embrace BIM, but further development is needed to fully optimize the use of BIM in their operations.	The contractor has achieved a high level of organizational maturity in their BIM process, showcasing a comprehensive and well-established approach to BIM implementation. They have a structured and well-documented BIM process that is consistently applied across projects and departments. The contractor demonstrates a proactive mindset in continuously improving their BIM processes and workflows, seeking opportunities to streamline collaboration, enhance efficiency, and leverage best practices. Their organizational culture supports the adoption of BIM, and they have a dedicated team responsible for overseeing BIM implementation and driving innovation in this area.
10.3	**Collaborative practices**	The contractor actively engages in collaborative work within the company, utilizing collaborative platforms for document management and synchronized modeling. They have defined policies and processes for version control, permissions, and intra- and inter-organizational sharing. They employ relevant technologies for intra- and inter-organizational collaboration.	The contractor demonstrates a high level of commitment to collaborative work. They effectively utilize collaborative platforms for document management and synchronized modeling, ensuring efficient authorization and security management. They have well-defined policies and processes for version control, permissions, and intra- and inter-organizational sharing. They leverage advanced technologies for seamless intra- and inter-organizational collaboration.
10.4	**BIM Personnel**	The contractor has a team with a significant number of employees experienced in BIM implementation, including those with specialized BIM training. The company has dedicated internal teams for BIM processes.	The contractor has a highly skilled team with extensive experience in BIM implementation. They have a considerable number of employees with BIM training, and their internal organization includes dedicated teams for BIM processes.
10.5	**BIM Technologies**	At the contractor level, there is a moderate level of understanding and implementation of BIM technologies. They have a basic understanding of the available BIM technologies and their application within the project. However, there may be some areas where further development or training is needed to enhance their proficiency in utilizing BIM technologies to their full potential. The contractor demonstrates a willingness to adopt BIM technologies but may require some support and guidance to fully integrate them into their workflow.	At the contractor level, there is a high level of understanding and implementation of BIM technologies. They have successfully implemented BIM workflows in previous projects, demonstrating their ability to leverage BIM technologies to improve project coordination, data management, and collaboration. The contractor has established effective processes and procedures to ensure the seamless integration of BIM technologies throughout the project lifecycle. They stay updated with the latest advancements in BIM and continuously seek innovative ways to enhance their BIM capabilities and deliver high-quality projects.
10.6	**Expected Future Performance**	The contractor is expected to have a moderate level of experience and understanding in implementing BIM - some recommendation letters to support this were delivered. They are capable of utilizing BIM for various aspects of the project, such as cost estimation, schedule management, and quality control. While the contractor's use of BIM is expected to contribute to project performance, there may be some uncertainties or areas for improvement in fully realizing the benefits of BIM. Trust and credibility in the contractor's ability to effectively utilize BIM are moderate.	The contractor is expected to demonstrate a high level of competency and proficiency in utilizing BIM across the project lifecycle - a significant number of recommendation letters to support this were delivered. They are expected to effectively leverage BIM for cost estimation, schedule management, quality control, and other project-related activities. BIM is expected to be fully integrated into their processes, resulting in enhanced accuracy, efficiency, and collaboration. The contractor's expertise in utilizing BIM is expected to significantly contribute to a high level of project performance. Trust and credibility in the contractor's ability to deliver cost-effective, timely, and high-quality outcomes through BIM implementation are high.

Appendix 2. BIM-integrated framework: evaluation criteria value tree.

- Evaluation Criteria
  - Bid Financial (BID)
    - Overall price
    - Price change
    - Unbalanced bid
    - Calculation mistake
    - Financial reservation
    - Financial schedule
  - Bid Schedule (BID)
    - Overall time
    - Time change
    - Work program
      - Network diagram
      - Financial compatibility
    - Equipment and manpower
  - Bid Technical (BID)
    - Technical report
    - Quality plan
    - Environmental plan
    - Safety plan
  - Technical Ability (BID)
    - Organizational structure
    - Personnel qualification
    - National manpower
    - Subcontractors
    - Construction methods
    - Reservations
    - Joint venture
  - Bid Understanding (BID)
    - Aware of bid
    - Explain ambiguous
    - Response ambiguous
  - Alternative Offer (BID)
    - Cheaper bid_no advance payment
    - Cheaper bid_with advance payment
    - Shorter period_with payment
    - Shorter period_no payment
    - Better quality
  - Project Location (BIDDER)
    - Site proximity
    - Site familiarity
  - Experience record (BIDDER)
    - Number of years
    - Total work volume
    - Average work volume
    - Different contract types
  - Expected performance (BIDDER)
    - Financial
    - Schedule
    - Quality
    - Environmental
    - Safety
    - Clients relationship
    - Subcontractors relationship
    - Suppliers relationship
    - Insurers relationship
    - Cooperation in problem solving
  - BIM (BID)
    - BIM Price
    - BIM Financial schedule
    - Master Information Delivery Plan (MIDP)
    - BIM Execution Plan (BEP)
    - Collaborative work
    - BIM Human resources
    - BIM Software and Hardware
    - Hardware
  - BIM (BIDDER)
    - BIM Experience record
    - BIM Process and Maturity
    - Collaborative practices
    - BIM Personnel
    - BIM Technologies
    - Expected BIM performance

Appendix 3. Case study BIM-integrated framework: evaluation criteria value tree.