Multi-Criteria Decision Analysis as a Supporting Tool for Decision-Making in Construction Projects

Master's thesis in Design and Construction Project Management

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Master's Thesis ACEX30

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“A decision is a judgment. It is a choice between alternatives. It is rarely a choice between right and wrong. It is at best a choice between “almost right” and “probably wrong” – but much more often a choice between two courses of action neither of which is probably more nearly right than the other.”

— Peter F. Drucker, in The Effective Executive (1967)

Preface

In this study, Multi-Criteria Decision Analysis (MCDA) has been explored through literature reviews, a case study, interviews, questionnaire, and tool development. The work has been carried out from January to June 2024. The report is the result of a master's thesis of 30 ECTS in the master's programme of Design and Construction Project Management.

The work has been conducted at the department of Architecture and Civil Engineering, division of Construction Management, at Chalmers University of Technology, Sweden. The project has been carried out with Researcher Yutaka Goto and Adjunct Professor at Construction Management Christina Claeson-Jonsson as supervisors and Full Professor Holger Wallbaum as examiner.

First and foremost, we extend our heartfelt thanks to Yutaka Goto and Christina Claeson-Jonsson, whose invaluable academic guidance and professional assistance have been the cornerstone of this study. Further, we would like to thank Holger Wallbaum for giving valuable support.

We also want to express our gratitude toward the respondents who generously shared their time and experiences in our interview study and questionnaire, enriching this work with their perspectives.

Finally, we would like to our friends and family, your unwavering support has been our anchor throughout this process.

Jesper Hjort and Rodrigo Giorgi, Gothenburg, June 2024

Multi-Criteria Decision Analysis as a Supporting Tool for Decision-Making in Construction Projects

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Abstract

The construction industry faces significant environmental and financial challenges, driven by high greenhouse gas emissions, intensive energy consumption, and rising resource costs. This thesis explores the role of Multi-Criteria Decision Analysis (MCDA) in managing project complexity and improving decision-making processes. MCDA integrates multiple criteria and stakeholder perspectives, facilitating structured and rational decision-making crucial for the dynamic construction environment. The research employs both qualitative and quantitative methods, including 8 interviews and questionnaires with key stakeholders, with the purpose to develop an MCDA prototype using Analytic Hierarchy Process (AHP) and Simple Additive Weighting (SAW) methods.

The findings demonstrate that MCDA aids project teams in structuring, analysing, and deciding on complex issues, leading to informed decisions aligned with project goals. Specifically, MCDA facilitates clear prioritization of sustainability targets, as evidenced by the consistent recommendation for timber cladding. It also showed how utilizing MCDA as a tool minimizes stakeholder conflicts through transparency and traceability of decisions, enhances the ability to address unforeseen challenges, and supports robust planning for future uncertainties. Consequently, MCDA leads to a streamlined decision-making process, improved stakeholder consensus, and effective handling of complex construction project dynamics.

The case study shows that clear project goals and effective stakeholder management lead to consistent decision recommendations. MCDA in this sense improves decision-making quality but can also be a demanding tool in terms of time and cognitive efforts for participants. This suggests a need to explore other MCDA methods for varying scenarios to better understand the effectiveness of MCDA.

Key Words: Construction Industry, Project Complexity, Stakeholder Management Decision-making, Multi-criteria Decision Analysis (MCDA).

Beslutsanalys med flera kriterier som ett stödverktyg för beslutsfattande i byggprojekt

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Sammanfattning

Byggnadsindustrin står inför betydande miljömässiga och ekonomiska utmaningar, drivna av höga växthusgasutsläpp, intensiv energiförbrukning och ökande resurskostnader. Denna avhandling utforskar rollen av Multi-Criteria Decision Analysis (MCDA) i hantering av projektkomplexitet och förbättring av beslutsfattandeprocesser. MCDA integrerar flera kriterier och intressentperspektiv, vilket underlättar strukturerat och rationellt beslutsfattande som är avgörande för den dynamiska byggmiljön. Forskningen använder både kvalitativa och kvantitativa metoder, inklusive 8 intervjuer och enkäter med nyckelintressenter, med syftet att utveckla en MCDA-prototyp med hjälp av Analytic Hierarchy Process (AHP) och Simple Additive Weighting (SAW) metoder.

Resultaten visar att MCDA hjälper projektteam att strukturera, analysera och fatta beslut om komplexa frågor, vilket leder till välgrundade beslut som är i linje med projektmålen. Specifikt underlättar MCDA tydlig prioritering av hållbarhetsmål, vilket framgår av den konsekventa rekommendationen för träbeklädnad. Det visade också hur användning av MCDA som ett verktyg minimerar intressentkonflikter genom transparens och spårbarhet i besluten, förbättrar förmågan att hantera oförutsedda utmaningar och stödjer robust planering för framtida osäkerheter. Följaktligen leder MCDA till en strömlinjeformad beslutsprocess, förbättrad intressentkonsensus och effektiv hantering av komplexa byggprojekt.

Fallet visar att tydliga projektmål och effektiv intressenthantering leder till konsekventa beslutsrekommendationer. MCDA förbättrar i detta avseende beslutsfattandekvaliteten men kan också vara ett krävande verktyg i termer av tid och kognitiva ansträngningar för deltagarna. Detta tyder på ett behov av att utforska andra MCDA-metoder för varierande scenarier för att bättre förstå effektiviteten av MCDA.

Nyckelord: Byggnadsindustrin, Projektkomplexitet, Intressenthantering, Beslutsfattande, Multikriteriell beslutsanalys

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LIST OF ACRONYMS

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

AHP	Analytic Hierarchy Process
CO2	Carbon Dioxide
IPD	Integrated Project Delivery
KPI	Key Performance Indicators
MAMCA	Multi-Actor Multi-Criteria Analysis
MAMCDA	Multi-Actor Multi-Criteria Decision Analysis
MCDA	Multi-Criteria Decision Analysis
SAW	Simple Additive Weighting

CHAPTER 1

INTRODUCTION

SUMMARY

This chapter introduces the overarching topic of the thesis, emphasizing the environmental and financial challenges faced by the construction industry. It outlines the need for more sustainable practices and the role of Multi-Criteria Decision Analysis (MCDA) in improving decision-making processes within the sector. The chapter sets the stage for the research by stating the aim, objectives, and research questions, highlighting the study's relevance and importance.

1.1. Background

The construction industry faces major environmental challenges, marked mainly by high greenhouse gas emissions and intensive energy consumption. Boverket, the Swedish housing agency, has revealed data highlighting the significant environmental impact of the construction sector. According to Boverket´s report, approximately 22 per cent of Sweden´s total environmental emissions can be traced to the construction sector (Boverket, 2024). These environmental challenges arise from a variety of sources, including the complexity of construction operations, the use of materials and building techniques. The need for a shift to more environmental practices in the industry is highlighted by the sector's environmental impact.

On the other hand, financial factors likewise play a crucial role in driving changes in the construction sector. Rising resource costs and the need for operational efficiency drive organisations to seek innovations and adaptations (McKinsey & Company, 2021). However, balancing short-term profitability with long-term environmental sustainability is present as a challenge, especially for construction companies, where pressures for immediate results often clash with the investments required for sustainable practices (Gassmann & Jackson-Moore, 2023).

Recently, the construction industry has faced a surge on demand for sustainable practices. This increase is driven by both governmental regulations and an environmental awareness among clients. This scenario reflects not only a rising environmental consciousness but also a need for the industry to adapt to the new context (McKinsey & Company, 2021). Contractors are being challenged to develop sustainable strategies and rethink their business plans to effectively incorporate sustainable practices in a way of not being simply a matter of environmental responsibility, but also to become a competitive differentiator, offering an advantage in an increasingly aware and demanding market (Reinhardt, 1999).

The integration of environmental sustainability faces the challenge of managing and satisfying a diverse array of stakeholders' expectations, each with their own objectives and values, and reflects into a range of performance criterion relevant in the current context, marked by growing environmental pressures and market demands for ecological responsibility (Bocken et al., 2014). Understanding and addressing these varied perspectives becomes crucial for developing solutions. Thus, this multifaceted approach is essential for driving changes in the industry, balancing the need for environmental sustainability with business goals and stakeholder expectations (Bocken et al., 2014).

Traditionally, decisions in construction have been influenced primarily by financial factors, often guided by the managers' intuition and past experiences with similar projects. However, this reliance on intuition and previous experiences does not always yield the best results, as each construction project has its unique characteristics and aspects (Poon & Price, 1999). The development of Multi-Criteria Decision Analysis (MCDA) has in that sense been used as an effective approach for solving complex decision problems. It offers a more holistic methodology, enabling project managers to systematically evaluate and balance various relevant factors in their decisions process.

Multi-Criteria Decision Analysis (MCDA) is a discipline that assists in decision-making processes involving multiple, often complex, and conflicting criteria. According to Ishizaka & Nemery (2013) MCDA integrates elements from various fields including mathematics, management, informatics, psychology, social science, and economics, and its applications are extensive, catering to both tactical, operation and strategic decisions depending on the time perspective of the outcomes. In addressing these complexities, MCDA facilitates nuanced decision-making by allowing project managers to systematically evaluate multiple conflicting criteria, thus supporting more informed and strategic decision processes. This method's relevance is underscored in complex decision scenarios typical in construction, where decisions made during the initial project stages can have extensive implications throughout the project lifecycle (Dodgson et al., 2009).

This thesis addresses the decision-making processes that are an important aspect of facing the construction sector's complex structure and meeting new requirements. The role of Multi-Criteria Decision Analysis (MCDA) in promoting more effective decision-making stands out, in contrast to traditional decision approaches.

1.2. Aim and Objectives

The primary aim is to understand the role of MCDA in managing project complexity and to evaluate its effectiveness in improving decision-making processes. Specifically, the thesis will:

1. Identify the complexities in construction projects and analyse how MCDA method can improve the decision-making process.
2. Collect quantitative data to establish an MCDA prototype for a case study.
3. Gather qualitative data through interviews to understand the subjective perspectives, experiences, and processes of decision-making from stakeholders within a construction project.
4. Evaluate a case study to demonstrate how MCDA can be used to navigate complexity within the decision process.

1.3. Research Questions

The research questions are designed to investigate how MCDA supports project managers in navigating complex decisions and balancing diverse stakeholder values. The research questions stated for this study are:

I. How can construction projects benefit from using MCDA to evaluate different scenarios?

II. How does the inclusion of stakeholders' perspectives impact the decision-making process in construction projects when using MCDA?

1.4. Relevance and Importance of the Study

This thesis bridges the gap between theoretical MCDA frameworks and their practical application in construction projects, particularly within the Swedish context. The motivation for this research stems from the pressing environmental and financial challenges faced by the construction industry, where long-term sustainability goals conflict with short-term financial benefits. By addressing these challenges, the study aims to enhance decision-making quality and stakeholder management through empirical evidence of MCDA's effectiveness.

This research contributes new insights by integrating multiple criteria and stakeholder perspectives, offering a structured approach to navigate project complexities. It builds on existing research by applying MCDA in a real-world case study.

The study addresses a gap in the literature by demonstrating how MCDA can be effectively used in construction projects to balance multiple, often conflicting criteria. The findings suggest avenues for future research and practical improvements, making it highly relevant for both researchers and practitioners. Ultimately, this study enhances the understanding of decision-making in construction, improving decision quality and stakeholder inclusion.

1.5. Delimitations

- **Data Availability**: The outcomes and the depth of the analysis of this research are results of the availability and reliability of data. Access to comprehensive, accurate, and timely data from the construction project and its stakeholders is often limited. The selection of stakeholders for the interviews may also restrict the perspectives included in the research.
- **Scope of MCDA Approach**: The study focuses on the specific MCDA techniques of Analytic Hierarchy Process (AHP) and Simple Additive Process (SAW). AHP was selected due to its simplicity and flexibility, which through a pair-wise comparison analysis, allows it to be adapted specifically to each field of application without requiring great expertise from the decision maker. This technique is easily combined with other methods and is often used to weigh the importance of criteria that define the decision problem. SAW was chosen for its straightforward approach to decision-making in multi-criteria analysis. This technique integrates the scores of various criteria with their corresponding weights into a single value, which is then used to rank each alternative. SAW is favoured for its simplicity, ease of use, and the clarity of its results. It can also be easily adapted to the specific context of this study. However, the exclusion of other MCDA techniques restricts the possibility to gain different insights and advantages that other methods may have that could be suitable for other types of decision scenarios.

- **Geographical Context**: The research is specifically focused on Swedish construction. This geographical limitation means that the findings may not be generalizable to other regions or countries with different environmental, economic, cultural, and regulatory contexts.

1.6. Thesis Structure Overview

The thesis is organised into several key chapters. Chapter 1 introduces the topic and frames the research aim and objectives. Chapter 2 details the methodology, including data collection methods. Chapter 3 provides a literature review of the construction project complexities and challenges and specifies the theoretical foundation of MCDA, why certain methods were selected and how they are used. Chapter 4 presents the case study results, and chapter 5 discusses the findings. Finally, chapter 6 concludes with the implications of the findings and suggest future research.

CHAPTER 2

METHODOLOGY

SUMMARY

This chapter presents the methodology applied in this research and outlines the reasons and motivations for choosing this specific research approach. Subsequently, the research methods are explained, describing the data collection and analysis procedures that served as the basis for the development of the thesis. This section also addresses the ethical considerations pertinent to the handling and use of the information obtained

2.1. Research Approach

For this study, which aims to investigate the decision-making process in projects in the construction sector, an abductive research approach was adopted, which, as described Bell et al. (2022), is a methodology that begins with the observation of phenomena, followed by the development of explanations through an interactive synthesis between theory and empirical data. This approach allows both quantitative and qualitative data to be used and is based on combining subjective interpretations with objective analysis. Rather than following a linear sequence, this methodology is characterized by a back-and-forth process, adjusting theories as new data is collected and analysed. As a strategy for this research, the principle of convergent mixed methods was integrated into the abductive approach, as outlined by Creswell and Clark (2017), where qualitative and quantitative data are collected simultaneously, analysed separately and then merged, allowing for a comprehensive analysis of the research topic.

Qualitative data was collected in two ways: deductively, through a literature review to understand the complexity of the construction sector and its impacts on the decision-making process; and inductively, through interviews with actors involved in the case project. These interviews allowed for a holistic and direct understanding of the dynamics between the parties involved in a construction project with regards to the factors that influence the decision-making process. With the results from the interviews and documents from the case study, a questionnaire could be structured and administered to the same participants as in the interviews.

The results of both the interviews and the questionnaires were integrated and analysed together with the literature review and case study, contributing to the development of the data evaluation model, which enabled the findings of this research to be formulated. The abductive approach facilitated a flexible and iterative process in which the theoretical and analytical framework was continually reoriented and developed in conjunction with the collection and analysis of empirical data. This method allowed the research questions and analytical framework to be adjusted appropriately as new data was incorporated, characterizing the approach of this research, as shown in figure 1.

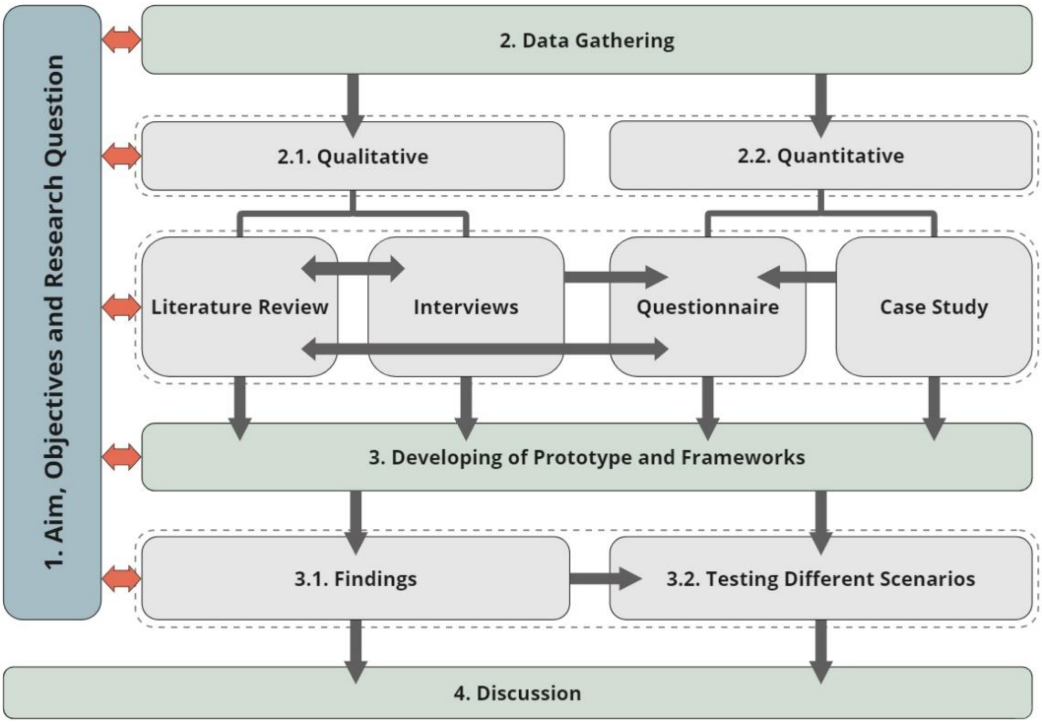

Figure 1: Overview of the research approach.

2.2. Case Study Description

The case study project, an office building located in Stockholm, Sweden, aims to achieve reduced emissions of 225 kg of CO2 per square meter, which corresponds to 50% of the typical emissions of new construction projects, which generally emit around 450 kg of CO2 per square meter (Fabage, 2024). The strategy to achieve this substantial reduction in climate impact includes the reuse of heavy construction components from a previous demolition project on the same site as the current project. In addition, the construction will incorporate the selection of materials according to their low-carbon properties, such as wooden elements.

The project also serves as a pilot project on behalf of the client and is one of the first projects to be developed as part of the research project "Återhus - Constructing Buildings from Buildings". The research initiative focuses on the reuse of heavy structural components, such as cores parts and concrete and steel facades, in new construction and renovation. The project involves the collaboration of 13 parties and has received support from the Swedish Innovation Agency, Vinnova. In the case of the study project, preliminary results indicate the possibility of reusing approximately 3,500 m² of hollow core slab elements, resulting in an estimated reduction of 300 tons of CO2.

The case study research evaluates the relationship between actors involved in the project, as well as investigating which criteria are relevant to the development of sustainable construction, and finally visualizing how the actors present different perspectives on the criteria and how this influences the decision-making process in projects. As at the conclusion of this study, the project has completed the Systemhandling (System Design) phase and is currently on hold before starting the Bygghandling (Construction Documentation) phase. The project is relevant to this study because, as well as having an approach focused on sustainability issues, it has also been conducted in a collaborative manner between the actors involved from the early stages of the project's life cycle. It is important to underline that this project has unique characteristics and caution should be exercised in interpreting the results of this analysis to avoid generalization of projects in the construction sector, where each project has a particular approach depending on the context.

2.3. Methodological Approach for Literature Review

The literature review, which began in the early stages of this study, focused on examining existing publications on the decision-making process in construction industry projects. The main aim of this review was not only to examine the main ideas and debates in the field, as highlighted by Bell et al. (2022), but also to obtain an overview of previous studies and identify areas that still require in-depth investigation.

Throughout the research, the keywords and literature selections were adapted to cover a broader scope, leading to the identification of areas in need of further investigation. Prior to the interview process, an initial literature review was carried out to build a knowledge base and expand perspectives on the challenges of project decision-making most effectively at this stage. After the interviews, a new review was necessary, adopting a dynamic process where new perspectives were included in the literature review based on the insights obtained.

To efficiently organize the information collected, a list of references and a database cataloguing publications with details such as authors, year, summary of main ideas, number of citations, keywords and search engines were drawn up. The criteria for selecting the literature were based on the timeliness of the research and relevance to the topic, with a preference for literature that had been widely cited. The main literature search tools included Google Scholar, Chalmers Library database, Scopus, and

ResearchGate, as well by using reference lists of relevant journal articles to guide the selection of additional literature. AI tools for network mapping of literature were also employed to explore and organize academic works using citation-based algorithms, which provide recommendations on similar, earlier, and later works, as well as suggestions of related authors, and for greater reliability of the results, double-checking of relevance was conducted in the academic databases cited previously. Publications were also selected through recommendations from the thesis supervisors, and from the bibliography of academic courses that address the topic of decision making.

2.4. Interview Study

To complement the qualitative data in this study, a series of semi-structured interviews were conducted using a case study approach, seeking to understand how the visions, dynamics, and perceptions of stakeholder criteria influence decision-making in construction projects. Semi-structured interviews have a core set of questions to ensure consistency between interviews but also have a flexible format that enables interviewees to discuss additional topics that arise spontaneously during the conversation. This allows for the inclusion of both open, general questions and more targeted ones if the answers are deemed meaningful, giving the interviewer freedom to explore additional themes suggested by the interviewee's answers, thus contributing to a richer and more detailed understanding of their perspectives (Bell et al., 2022).

To define the structure of the interviews, evaluations were conducted with the thesis supervisors to determine the most effective approach and its application to this study. The questions were the same for all the interviewees, and the semi-structured format allowed for varying the interaction according to the interviewees' answers and their roles in the project. The final set of questions can be found in Appendix A. The selection of interviewees was designed to capture a range of perspectives within the construction project studied and was supplemented by recommendations made by the interviewees themselves, who suggested other participants whose perspectives might be valuable to the research. In this way, eight key actors were interviewed, with varying roles and involvement from the early stages of the project, as shown in Table 1.

Table 1: Interview Schedule and Duration of the interviewee´s

Role in the Case Study	Interview Date	Duration
Business Manager	28/03/24	0:45h
Sustainability Specialist	02/04/24	0:45h
Sustainability Specialist	09/04/24	0:45h
Project Manager	10/04/24	0:45h
Structural Engineer	10/04/24	0:45h
Client	11/04/24	0:50h
Structural Engineer	11/04/24	0:45h
Architect	12/04/24	0:40h

The questions, along with a document describing the purpose of the interview, were sent to the interviewees in advance, ensuring that the participants were well prepared and familiar with the topics to be discussed. The interviews were conducted between March and April 2024 via the Teams platform, which facilitated both scheduling and conducting the sessions. They were carried out in both English and Swedish, depending on the interviewee's preference. The two authors of this thesis were present at all the interviews, each of which lasted between 40 and 50 minutes. Every session began with a brief description of the project and an explanation of how personal data would be managed in compliance with the GDPR. The interviewees were informed about the anonymization procedures that would be applied in the final report, and their permission was requested to record and transcribe the interviews. At the end of the session, the interviewees were informed that in addition to analysing their responses, a questionnaire would be sent out later. This questionnaire, based on the answers obtained from the different actors interviewed, aimed to collect quantitative values to complement this study for the development of an MCDA prototype. After the interviews concluded, the answers were synthesized and used later for the findings, discussion, and conclusions presented in this study.

2.5. Questionnaire Study

As this study aims to use comparative data in its analysis, the standardization of responses ensures that each participant answers the same questions in the same way, aiding direct comparison of data. In addition, the questionnaire used quantifiable scales of closed questions, which allow for statistical analysis and objective comparisons between the topics covered.

For this study, the questionnaire was distributed to the 8 actors involved in the interviews, using the QuestionPro platform. This tool was selected because it offers a wide variety of question formats, as well as facilitating the automation of response collection by allowing data to be exported in various format extensions. This simplified data management and integration with other programs used for analysis. This integration eliminated the need for manual coding, thus reducing the possibility of errors and the time required for data processing.

The questionnaire, formulated in English and detailed in Appendix B, began with an introduction that clarified its objectives, structure, and instructions for completing it. Different techniques were used to structure the questions: the Simple Matrix for questions where a single variable was evaluated in different contexts; the Bi-polar Matrix for questions that used pair-wise evaluation between two variables; Ordering for questions where respondents ranked items according to their priority; Multiple Choice questions where only one choice was allowed; and Rating with numeric control, where respondents indicated their answer on a numeric scale from 0-100.

2.6. MCDA Prototype

The MCDA prototype developed in this study was based on data collected through interviews and questionnaires, providing a foundation for the prototype's development. This prototype uses two different methodologies: AHP (Analytic Hierarchy Process) and SAW (Simple Additive Weighting). The stages of the prototype's development are described below.

Decision Context and Identification of Alternatives

The first stage involved identifying the context of the decision to be analysed based on the interview study. The alternatives to be evaluated were identified according to the data provided by the partnering company. This initial step served to define the scope of the analysis and ensure that all relevant alternatives were considered.

Analysing the Raw Data and Pairwise Comparison (AHP)

The raw data obtained from the questionnaire was analysed in order to formulate a pairwise comparison study using the AHP methodology. Based on the results of the AHP, the criteria that had more significance serve as the basis for evaluating the alternatives were identified.

Selection of sub-criteria: Based on the criteria established, the sub-criteria relevant to the context of the prototype decision were selected.

Defining the Weights of the criteria

Using a scale of 0 to 100, the relative weights of each sub-criterion were determined according to the responses in the questionnaire from the actors involved in the project.

Defining the Alternative Scores

For each alternative, scores were set for the sub-criteria identified. This process involved assigning values based on data provided by the partnering company, data from suppliers and data from the literature and government agency.

Combining Values and Evaluating Scenarios (SAW)

With the scores and weights of the criteria for each alternative defined, the values were combined by data arrangements using the SAW methodology. The prototype was designed to test the results of the MCDA in various scenarios, allowing the weights of the criteria and the values of the scores to be altered.

Evaluation of Criteria Weights: Different arrangements of actors were employed to evaluate the relative weights of the criteria. Various scenarios were created in which the weights assigned by each actor were altered to observe the impact on decisions.

Evaluation of Alternative Scores: Hypothetical scenarios were developed with the scores altered according to specific events, making it possible to analyse how different values impact the results.

Sensitivity Analysis

The sensitivity analysis of the prototype seeks to assess how changes in the weights of the decision criteria and the scores of the alternatives affect the results of the MCDA. To do this, mathematical methods were used to identify which change in criterion weight could alter the result. The process involves calculating the minimum weight change, checking its feasibility, and analysing the results to identify the critical criteria.

Technical Implementation

The prototype was developed using Excel software as the main tool, where mathematical formulas from the different MCDA methodologies used for this study were applied, as presented in sections 3.5.4; 3.5.5 and 3.5.6. The raw data derived from the answers obtained in the questionnaire sent to the different case study actors involved in this study.

2.7. Ethical Considerations

The content presented in this thesis was developed with respect for ethical standards relating to citations and references, ensuring that all credits were correctly attributed to the original authors and researchers, and maintaining the integrity of intellectual property.

All the participants involved in this study consented to their inclusion, and measures were taken to ensure the confidentiality and impartiality of the data collected. It was decided by the authors of this study that both the names of the interviewees, the companies they work for, and the project that was used as the case study were omitted in order to prevent any kind of bias corresponding to this information. The focus of the study was not to evaluate the performance of those involved in the case study, but rather to use it together with the interviews and questionnaire as an analytical tool to understand decision-making processes in a real context and foster relevant discussion on the topic.

The interviews conducted were recorded and transcribed with the prior authorization of the participants, and these transcripts were treated with the highest fidelity to the answers provided. To avoid any misunderstandings or conflicts, the interviewees confirmed their personal information, such as names, positions, and the company they work for. A confidentiality agreement was signed between the students, supervisors and the company collaborating on this thesis, ensuring the protection and integrity of the information shared during the research.

CHAPTER 3

LITERATURE REVIEW

SUMMARY

The literature review chapter forms the foundation of this study by examining existing research relevant to the topic under investigation. This chapter aims to provide an overview of the current knowledge, identify gaps in the literature, and establish the context for the research questions.

3.1. Construction Project Complexity

In general, it is possible to see fragmentation in the construction industry coming from two areas present in the life cycle of a building: The project process and the building construction process itself (Nawi et al., 2014). Fragmentation is particularly evident during project development. In this context, the focus is mainly on the initial phases of a project, where there is both complexity and a need for coordination and collaboration between the actors involved.

3.1.1. Understanding Project Complexity

The complexity of a project is seen as a result of the different functions that occur between its participants, as well as the interdependence of its systems and subsystems and the effects of the decision made across the project stages (Lafhaj et al., 2024). The development and design of a building can be considered inherently complex due to its multifaceted and fragmented nature, where there is the interdependent involvement of several stakeholders, aiming to meet requirements and regulations along with the need to balance multiple, and often conflicting criteria. In this scenario, project obligations are also added to adhere to local construction codes, standards, and regulations, while at the same time making an effort to ensure that the interests and demands of end users, client and society in general are accomplished (Jansson et al., 2013).

Jansson et al. (2013) further add the existence of operational islands, which can be seen as distinct and isolated workflows within different project disciplines that hinder communication and coordination between the actors involved. These islands create gaps in the design process, leading to inefficiencies such as repeated design iterations, increased rework, and a general misalignment between the project outcome and its initial goals. These attributes give a unique character to the project process, where complexity characteristics are highlighted. And as described by Ahn et al. (2017), project complexity is related to the multiplicity of interrelated parts, processes, actors, systems, and technologies, and is correlated with the difficulty of managing a project and predicting results.

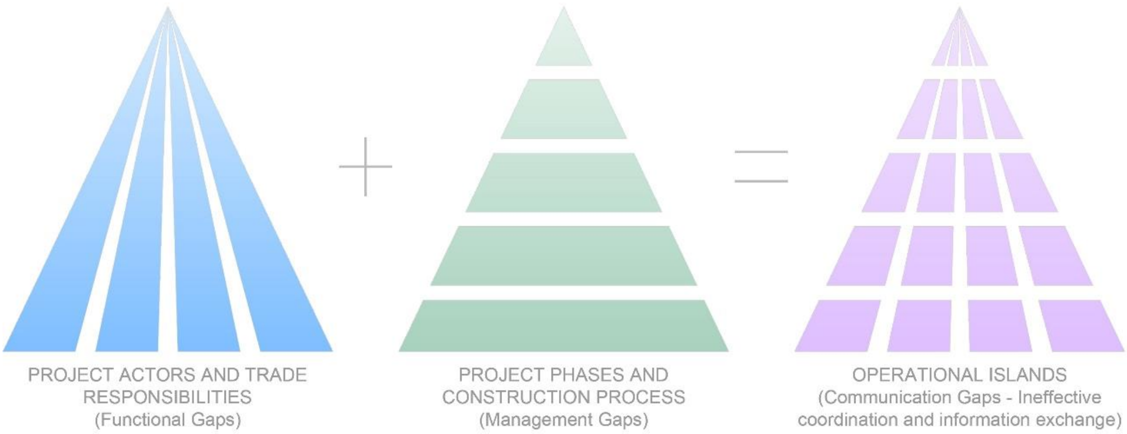

Figure 2: Operational islands (Jansson et al., 2013)

3.1.2. The Nature of Complexity in Construction Projects

It is important to establish what defines complexity in the context of construction. In this study, complexity is not referring to something being simply complicated, but the dynamic of interdependencies and unpredictable results. This is due to the multifaceted and interrelated nature of the elements within a system, which complicates understanding, prediction, and management (Baccarini, 1996). Thus, complexity is characterized not only by the number of parts, but by the countless ways in which these parts interact and influence each other, leading to behaviours that are not apparent from the individual components.

Project complexity, therefore, occurs when the network of interdependencies and interactions extends to the domain of project management, incorporating a spectrum of challenges that encompass technical, organizational, and environmental dimensions (Qazi et al., 2016). Specifically, in construction projects, complexity is stressed by the unique characteristics of the sector, including the temporal nature of project teams, the variability of external conditions and factors, and the high degree of technical expertise required (Baccarini, 1996). Adding to the discussion, Bosch-Rekveldt et al. (2011), mention the need to coordinate a wide range of disciplines, manage extensive regulatory requirements and address environmental impacts and sustainability concerns are factors that amplify the complexity of projects.

Technical Complexity

Technical complexity refers to the challenges of a project that are related to engineering and technological aspects, including factors such as the degree of technological innovation employed, the interdependencies of technical components, the clarity of project objectives, the scope and technical risks connected to the complexity of tasks. This complexity may involve requirements for the integration of advanced technologies, along with the management of component interdependencies, increasing the degree of uncertainty in solutions and technical results (Bosch-Rekveldt et al., 2011). Furthermore, the adoption of new technologies implies the need to constantly update teams' technical knowledge, as well as adapt work methods to incorporate these innovations effectively (Lafhaj et al., 2024).

Organizational Complexity

Organizational complexity, in turn, encompasses the challenges of coordination and communication of different teams and resources involved in the project, requiring effective communication and collaboration between various disciplines and stakeholders (Luo et al. 2017; Qazi et al. 2016). Projects with high organizational complexity typically face coordination and communication difficulties, requiring a diverse range of specialized knowledge and deal with multiple layers of management and decision-making (Bosch-Rekveldt et al., 2011). Vidal & Marle (2008) complement by stating organizational complexity significantly impacts project management, requiring careful management to avoid negative impacts on project results.

Environmental Complexity

Environmental complexity focuses on external factors and conditions that influence the project process, including the socio-political context in which the project is inserted, the regulatory environment, market conditions, diversity and interests of stakeholders, geographic and logistical challenges, and environmental risks (San Cristóbal et al., 2018). The greater the environmental complexity, larger will the need to manage stakeholder relationships and adapt to changes in external conditions that may affect project results (Bosch-Rekveldt et al., 2011).

Interplay of Complexity Dimensions

Understanding the interaction between these dimensions - technological, organizational, and environmental - is crucial for effective project management, as it allows managers to identify and address the specificities that are interconnected and influence each other, impacting the overall complexity of a project and its management and execution (Bosch-Rekveldt et al., 2011). For example, technical decisions can have organizational and environmental implications, while external environmental factors can introduce new technical and organizational challenges. This interrelationship accentuates the difficulty in managing construction projects, highlighting the need for a holistic approach that considers all aspects of project complexity.

3.1.3. Holistic Management Strategies

Adopting holistic management strategies is crucial for effective project administration, emphasizing the importance of identifying and managing complexities not only to mitigate challenges, but also as opportunities to improve performance, aiming for more competent administration to achieve better project results. This approach involves adaptive communication, careful team selection, and development of relevant skills, underlining the importance of understanding and holistically managing complexity (Luo et al. 2017; Qazi et al. 2016).

Jansson et al. (2013) highlight that holistic strategic approaches not only facilitate better stakeholder communication and engagement, transparent management of requirements, and interdisciplinary comprehensiveness in design, but also allow teams to be effectively incorporated across project complexities. This combination ensures achievement of project goals within time, cost, and quality constraints, while accommodating the dynamic interplay between the technical, organizational, and environmental dimensions of the project.

3.2. Who are the Stakeholders

Construction projects involve a diverse array of stakeholders, constituting a multifaceted and extensive assembly, ranging from governmental bodies, clients, architects, contractors, subcontractors, engineers, suppliers, communities, regulatory agencies, and the list goes on. This intricate network reflects the complex nature of construction projects (Akeyo Forsman, 2017). According to Bahadorestani et al. (2020) project stakeholders encompass organisations, groups, or individuals capable of impacting, being impacted by, or perceiving positive or negative effects from the project. Thus, the increasing involvement of stakeholders in the project also increases the complexity of the project´s management and coordination efforts, as each stakeholder brings its unique perspectives, interests, and requirements. Often leading to conflicts and disagreements. Consequently, effectively navigating the diverse interests becomes paramount for the success of construction projects.

3.2.1. Stakeholder Management

In construction projects, stakeholder management plays a critical aspect that could significantly impact project outcomes. Oppong et al. (2017) highlight how stakeholders possess a wide array of interests that must be addressed during project delivery, as they have substantial influence over project outcomes. For effective stakeholder management, it is essential for project managers to navigate the complexity of stakeholders and their interests to ensure that the decisions made throughout the project maximize the project´s value to the stakeholders involved.

In that sense, the concept of project success becomes multifaceted and can vary depending on the stakeholders' perspectives. Lim & Mohamed (1999) observed that the stakeholders' satisfaction with project outcomes carried more weight than strictly adhering to predetermined criteria. For example, the Sydney Opera house, despite its exceeding time and cost requirements (estimated cost of $7 million, final cost $102 million, and took 15 years to build instead of the estimated 4 years) was seen as a success by the public. On the other hand, while Heathrow Terminal 5 successfully met the British Airports Authority's objectives within the prescribed budget, timeline, and quality standards, it faced operational challenges that led to a negative perception among other stakeholders (Davies, 2016). This highlights the disparities in how different stakeholder groups define project success and emphasises the importance of satisfying all stakeholders involved.

Despite the importance of stakeholder management, construction projects often lack effective approaches to manage stakeholders. Akeyo Forsman (2017) emphasises several challenges stemming from ineffective stakeholder management, such as difficulty identifying stakeholders, inadequate stakeholder engagement and unclear stakeholder management goals. Furthermore, Akeyo Forsman (2017) suggests that companies that plan stakeholder management strategies achieve favourable results in project implementation.

3.2.2. Stakeholder Engagement

Engaging stakeholders is necessary for comprehending their objectives and concerns, thereby enhancing acceptance of decisions, and reducing project failure risks. Furthermore, stakeholder involvement facilitates the recognition of shared interests and conflicts, fostering a collaborative decision-making environment (Huang et al., 2021). Stakeholder engagement is increasingly acknowledged as pivotal for project success (Bal et al., 2013). Effective engagement necessitates the identification of stakeholders, understanding their interests and priorities, and actively involving them in decision-making processes. This approach not only mitigates conflicts but also enhances stakeholder satisfaction and encourages collaboration. Moreover, as explained by Bal et al. (2013), successful stakeholder engagement requires integrating stakeholder analysis, which considers their level of interest, power, and attitude towards the project to facilitate an effective decision-making process.

3.2.3. Stakeholder Identification and Categorization

Stakeholder identification is an essential part of the project management’s role to manage stakeholders, as it recognises and understands the stakeholders’ interests and impacts on project outcomes. Aapaoja & Haapasalo (2013) describe stakeholder identification as essential for navigating stakeholder management within the complex and unpredictable environments typical for construction projects and specify that the goal is to enhance the process of making decisions by incorporating the views and perspectives from stakeholders involved.

Olander (2007) emphasise that there can be several approaches to identify and categorize stakeholders, where one of them is to divide stakeholders into two categories. The internal and the external stakeholders. The division between the two is to organise and understand the different roles and influences stakeholders have on a project.

- **Internal stakeholders**, or primary stakeholders, are those who are formally part of the project coalition, such as project team members, management, and direct beneficiaries of the project. These stakeholders have direct control over resources and are actively involved in the project execution, making their support crucial for the project's success (Aapaoja & Haapasalo, 2013; Olander 2007).
- **External stakeholders**, or secondary stakeholders are on the other hand, not a direct party in the project but can influence or be influenced by the project outcomes. Examples include local communities, regulatory agencies, and non-governmental organizations. These stakeholders do not control project resources but have the potential to impact the project positively or negatively through their reactions, expectations, and demands (Aapaoja & Haapasalo, 2013).

Olander (2007) and Aaltonen et al. (2008) emphasize the importance of accurately identifying stakeholders to facilitate effective managerial decision-making. This involves understanding the various ways stakeholders can influence the project and recognizing the necessity of incorporating their perspectives into the project management strategy. Aapaoja & Haapasalo (2013) further highlight the significance of stakeholder identification, classification, analysis, and management approaches to navigate the complex stakeholder landscape. Moreover, Bourne & Walker (2005) argue that mapping stakeholders based on their legitimacy, power, and influence is fundamental to developing strategies that maximize positive impacts and minimize negative influences on the project. This underscores the critical role of stakeholder identification in project management and the success of project outcomes.

3.2.4. Stakeholder Salience

Building on the understanding of stakeholder identification, the concept of stakeholder salience emerges as a critical lens through which project managers assess and prioritize stakeholder needs and influences. Salience, defined by three key attributes — power, legitimacy, and urgency — serves as a guide for determining the degree of attention that stakeholders should receive throughout the project lifecycle. This approach aids in navigating the complex dynamics of stakeholder management by highlighting the attributes that elevate the importance of certain stakeholders' claims over others, making it easier for project managers to understand which stakeholders are of greater importance (Aapaoja & Haapasalo, 2013).

- **Power** is the capacity of stakeholders to influence project outcomes or enforce their will, often derived from their ability to organise resources, mobilize social or political forces, or affect the project's direction through their position or authority. Stakeholders with power can significantly impact the project's success, necessitating early identification and careful management (Aapaoja & Haapasalo, 2013; Aaltonen, 2010).
- **Legitimacy** pertains to the perceived appropriateness or acceptability of stakeholders' claims within a socially constructed system of norms, values, and beliefs. Stakeholders deemed legitimate are those whose interests, demands, or relationships with the project are viewed as justifiable or appropriate, making their engagement a matter of ethical consideration as well as strategic importance (Olander, 2006; Aaltonen, 2010).
- **Urgency** relates to the immediacy with which stakeholders' claims require attention, determined by the time sensitivity and the critical nature of their demands. Urgency accentuates the significance of timely and responsive engagement with stakeholders, particularly when their claims bear direct implications for the project's continuity and success (Aapaoja & Haapasalo, 2013; Aaltonen, 2010).

However, simply identify the stakeholders and assess their salience is not enough. It is equally important to have strategies in place to effectively respond to and act upon these insights. Olander (2007) explains how each stakeholder's position towards the project affects their impact on the decision-making process and how the concepts of impact and probability needs to be evaluated alongside with the stakeholder attributes. Building on the conversation, Aapaoja & Haapasalo (2013) introduces the impact/probability matrix (figure 3), a strategic tool used by project managers to categorize stakeholders according to the potential impact of their claims on the project and the likelihood of stakeholders acting. This matrix facilitates the prioritization of stakeholder engagement efforts, enabling managers to focus resources and attention on stakeholders who are most likely to influence the project outcomes.

Figure 3: Stakeholder impact/probability matrix, adapted from (Olander, 2007).

The matrix indicates the relation between stakeholders and the project, which can be used for project management to establish the stakeholder importance. The four quadrants represent stakeholder classification based on the impact they have on the project (Olander, 2007; Aapaoja & Haapasalo, 2013).

1. The “**Keep Satisfied**” stakeholders have a lower probability of acting but have a high impact. Their support is necessary; thus, it is important to ensure their satisfaction.
2. The “**Key Players**” are stakeholders with high level of impact and high level of probability to impact. These stakeholders are essential for the project success and need close attention and active engagement.
3. The “**Minimal effort**” stakeholder have low impact and low probability to act. They should be monitored but require less active engagement.
4. The “**Keep Informed**” stakeholders have a high probability to impact the project but the impact they have is lower. Here it is important to engage in communication and regular updates, to make them involved in the project process.

3.3. Decision-Making Challenges in Construction Projects

As presented in the previous sections, construction projects are considered complex due to their multifaceted and fragmented nature, requiring coordination and collaboration among multiple actors, as well as balancing conflicting criteria and adhere to regulations in an environment marked by interdependencies and the need for integration between systems and processes.

In this context, the decisions made during the various stages of a construction project have lasting impacts, affecting the entire life cycle of the project (Szafranko E. , 2017). Decision-making in projects aims to achieve objectives involving the project team using performance tools, while at the same time uncertainties and risks of alternatives, seeking satisfactory solutions for the delivery of results based on knowledge, experience, and evaluations of various criteria (Kerzner, 2023). Therefore, the choice of how (methods) and who (actors) should decide is as vital as the solution or decision adopted and can directly affect the success of the project (Kamari, 2023).

3.3.1. The Relation of Early Stages of Projects and Decision-Making

Given the complexity of construction projects, a diverse range of support methods is necessary to facilitate both data analysis and the decision-making process (Dziadosz &

Kończak, 2016). These methods include mathematical approaches, information and data management systems, as well as simulation and analysis models. By introducing these methods, it becomes possible to objectively analyse information, allowing decision-makers to evaluate options more accurately (Szafranko & Harasymiuk, 2022).

The applicability of these decision support systems, as highlighted by Marcher et al. (2020), is particularly interesting in the early stages of the project. These early stages are identified as having an opportunity to improve the decision-making process throughout the project life cycle. Schade et al. (2011) add that the importance of these stages is enhanced by the direct influence they have on project development, where effective and collaborative decisions are fundamental. They also stress the need for an interdisciplinary and iterative decision-making process from the early stages, which includes all the important stakeholders. This process is essential for better information sharing, allowing for a more precise evaluation of project alternatives that encompass both objective and subjective criteria.

Schöttle et al. (2018) add a perspective on how decisions made in early project phases shape and limit value creation processes throughout the project lifecycle. They advocate the importance of collaborative and traceable decision-making, which can increase the quality and acceptance of decisions by analysing interdependencies and their effects on project members, ensuring that all perspectives are considered.

3.3.2. Collaboration Challenges in Decision-Making

Therefore, a project depends not only on the effectiveness of the planning and design phases, but also on collaborative and well-informed decision-making from the beginning. According to De Andreis (2020), in the context of projects, decision-making is presented not as a solitary action, but as a team activity, where it is possible to consider elements ignored individually, facilitating the evaluation of previously unidentified alternatives, mitigating the possibility of errors, and creating more realistic expectations, since there is greater consideration of variables and impacts throughout the project's life cycle.

In contrast, Gerding et al. (2021) discusses the fact that a construction project is a temporary and inter-company project with multiple actors, where there are differences in interests and levels of influence that can hinder the decision-making process. This makes it necessary for there to be intense collaboration and frequent communication between the players involved.

Technological advances have significantly altered how information is collected, accessed, and processed, a fact that can be seen in the context of project management and the decision-making process. Kerzner (2023) points out that these advances have led to a scenario in which there is an excess of information, which in turn requires project managers to have the ability to differentiate between primary and secondary information and information that is dispensable to the project. In addition, the organization of control within projects can restrict access to crucial information, emphasizing the importance of effective communication in order to access information that is considered necessary; thus, decisions are often made based on partial information, which underscores the need for greater organizational efficiency.

Adding to the discussion, Adair (2010) emphasizes the importance of the ability to collect and filter relevant information, as well as the ability to discern what is essential from what is merely available during an excess of data, making the work of distinguishing between available and relevant information an essential process in the project to avoid hasty decisions without critical information.

On the other hand, Isaksson and Linderoth (2018) identify the lack of information as an obstacle, proposing that improving access to relevant information is a key element in enabling decision-makers to make more informed choices, which reinforces the need for effective information management strategies imposed by information overload and organizational barriers.

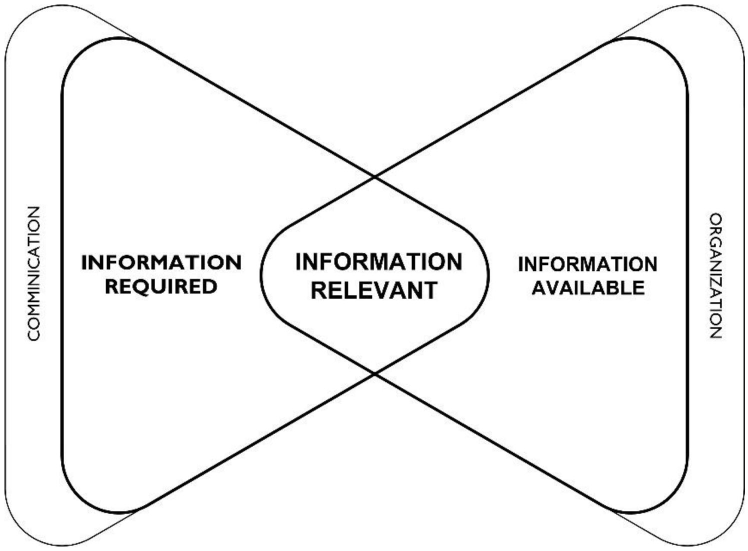

Figure 4: Complexity in the management of information that supports project decision-making. Based on (Kerzner, 2023; Adair, 2010; Isaksson and Linderoth, 2018)

Considering the convergence of these perspectives, we can highlight the existence of complexity in the management of information that supports project decision-making (figure 4). While Kerzner (2023) emphasizes the need for greater organizational efficiency and the importance of effective communication, Adair (2010) focuses on the ability to filter relevant information amid the multitude of data, and Isaksson and Linderoth (2018) complement this by pointing out the need to improve access to accurate and relevant information.

Effective decision making involves balancing multiple criteria and the preferences of different decision makers, recognizing that any improvement in a common goal requires the compromise of at least one other criterion, which implies a set of trade-offs to reach a consensual and optimized solution (Monghasemi et al., 2015). The awareness of the trade-off between the project's alternatives is an important aspect of construction project planning where task specifications, scope of work, resource forecasting, and activity scheduling are defined to optimize efficiency and performance (Anh et al., 2023).

Kerzner (2023) emphasizes that trade-offs are decision-making exercises where changes or sacrifices are made to one part of the project to benefit another. This practice is relevant when faced with the competing constraints of a project, where it is often necessary to balance different criteria. For the assessments of these trade-offs to be better analysed, it is necessary to have a more holistic knowledge of the project among the actors involved in the decision-making process. It is also pointed out that an integrated analysis can be carried out, which seeks to combine the best features of various alternatives into a single solution, underlining the need for a decision-making process that engages with the specific trade-offs of the project (Kerzner, 2023).

On the other hand, De Magalhães et al. (2019) focus on the importance of managing conflicts and trade-offs to achieve the project's objectives, emphasizing the adoption of methods and tools that allow for a proper balance between different and conflicting requirements. They describe trade-offs as conflicts between project objectives, where gains in certain aspects imply losses in others, highlighting the need for a consensus on criteria and alternatives, together with the use of multi-criteria methods supported by management tools for more informed decision-making, thus allowing for a more structured management of trade-offs (De Magalhães et al., 2019).

3.4. Beyond the Iron Triangle: Indicators for Construction Projects

The decision-making process, together with the evaluation criteria for the performance of results, are fundamental aspects of effective and successful project management. The concept of success in construction projects has been widely debated and has historically been dominated by the "Iron Triangle", which considers time, cost, and quality as the main performance measures (Pollack et al., 2018). This model has been fundamental in defining the criteria by which project managers seek the successful completion of projects, however changes in stakeholder demands and expectations have led to a re-evaluation of whether these criteria alone are sufficient to assess the success of a project (Toor & Ogunlana, 2010).

Originally, the Iron Triangle suggested that the success of a project could be assessed primarily by its ability to be delivered on time, on budget and according to the expected quality specifications. However, this perspective has proved limited in the face of contemporary challenges, especially regarding social and environmental responsibility (Ebbesen & Hope, 2013). Luo et al. (2017) add by arguing that project success indicators should be expanded to include criteria such as stakeholder satisfaction, environmental performance, and commercial value. Such measures reflect a more holistic understanding of project success, which transcends simple project execution and considers its long-term impact and contribution to society and the environment.

The factors that constitute a project's success are commonly referred to as key performance indicators (KPIs). These KPIs, essential for measuring and evaluating the performance of a construction project, include both objective and subjective indicators. Objective KPIs, such as time, cost, value, safety, and environmental performance, are calculated using precise mathematical formulas. On the other hand, subjective KPIs, which address aspects such as quality, functionality, and user satisfaction, are based on the opinions and judgments of the stakeholders involved in the project. This approach allows for a more comprehensive assessment of project performance, aligning success metrics with both the overall specific objectives of the project and traditional project management goals such as cost, time, and quality (Chan & Chan, 2004). However, as highlighted by Toor & Ogunlana, (2010), there is still a lack of consensus on a standardized set of KPIs for construction projects, stressing the need to adapt these indicators to the unique characteristics of each project in order to better capture the results of the project in question, and emphasizing the importance of a specific approach to the development and application of these indicators, whose systematic and well-integrated use is relevant to the effectiveness of project performance measurement.

The need to integrate sustainability into project management practices has gained prominence in recent years. With the increase in technological, financial and development process uncertainties, construction projects face a dynamic environment that requires more than just meeting deadlines and budgets (Chan & Chan, 2004). Ebbesen & Hope, (2013) put forward the idea of developing methods, tools and techniques to incorporate sustainability criteria into project management. This includes not only minimizing environmental impact, but also maximizing social and economic benefit.

As cited by Banihashemi & Khalilzadeh, (2020), one of the tasks of project managers is to plan the project so that they can carry it out to the highest quality and with the least time, cost, and environmental impact. And as discussed by Luo et al. (2017), the redefinition of performance criteria has also changed the role of the project manager, who in addition to managing time, cost and quality, managers now need to consider cultural relations, stakeholder management and environmental and social impacts, which in turn ends up requiring a more adaptive and sensitive approach to the context in which projects are carried out.

Therefore, we can say that addressing project criteria that go beyond cost, time and quality factors not only reflects a change in the perception of what constitutes a successful project, but also a transformation in stakeholders' expectations and demands of the construction industry. While the Iron Triangle remains a valuable tool, its application alone is insufficient to capture the complexity and multidimensionality of project results.

3.4.1. Sustainability in Construction

The concept of sustainability is rooted in sustainable development, as defined in the Brundtland Report by the World Commission on Environment and Development (WCED, 1987).This approach emphasizes the importance of meeting present needs without compromising the ability of future generations to meet theirs. Central to this idea is the triple-bottom line concept introduced by Elkington (1994), which involves economic development, environmental preservation, and social progress. These three aspects—

economic, environmental, and social—are fundamental to sustainability and are structured to be interdependent. Progress in one area should not impede advancement in the others. Sustainable development, therefore, requires a simultaneous consideration of these elements to ensure effective outcomes (Larsson & Larsson, 2020).

Sustainability not only considers growth and profitability to be important, but also demands that social objectives linked to environmental protection, social justice and economic development be achieved. Strategies and practices aim to meet the needs of stakeholders while protecting and improving resources for the future. Sustainability is assessed both quantitatively, by sustainable growth and material well-being, and qualitatively, by social and environmental well-being (Kudratova et al., 2019).

In recent decades, sustainability has become essential to the strategies of the actors involved in projects due to climate change, resource scarcity, global warming, and increased stakeholder awareness, where government initiatives and international organizations are increasingly focused on sustainable actions (Kudratova et al., 2019). Hart (1997) presents a model of four key aspects of a sustainability strategy: minimizing waste and pollution, designing products with minimal environmental impact, incorporating social and environmental well-being into business practices, and developing innovative clean technologies. This model forwards the idea that including these considerations in construction projects not only generates financial benefits for shareholders, but also strengthens social and environmental sustainability. By adopting sustainability principles, companies can create a win-win situation, increasing shareholder value and gaining a competitive edge.

In the context of construction, the development of sustainable buildings begins with the analysis of environmental conditions and available resources, not requiring design solutions to be perfect, but rather efficient in the use of these resources. These solutions can be improved over time, replacing fewer effective methods with more suitable ones, considering multiple options and analysing the consequences of decisions. Furthermore, the ability to choose between alternative courses of action is an important factor in directing systems towards sustainability, highlighting the relevance of effective decision-making in design management, as those decisions directly impact the quality of the final product (Kamari, 2023).

Kamari (2023) adds that sustainable construction requires a collaborative and iterative process from the earliest stages, involving multiple stakeholders such as architects, engineers from various specialties and contractors to align design decisions with sustainability objectives, as well as ensuring transparency and traceability of decisions. Larsson and Larsson (2020) complement this view, emphasizing the need to integrate multiple specialties in construction project management, which adds complexity due to the growing importance of sustainability. It is therefore crucial to start planning with clear and established sustainable criteria, where all stakeholders are involved from the beginning, adopting a more holistic and integrated approach, known as Integrated Project Delivery (IPD), which contrasts with more traditional methods that tend to involve stakeholders in a linear and progressive way (Kamari, 2023).

Thus, an adaptation of the MacLeamy curve (figure 5), which evaluates cost variations throughout the life cycle of a construction project (Ilozor & Kelly, 2012), shows that decisions aimed at sustainability, when implemented in the early stages, have a greater capacity to influence the outcome of the project, while the impact of these decisions on construction costs is relatively low. It is also possible to see that with the adoption of an IPD efforts and critical decision-making are more focused on the early stages of the project, where the possibility of changes is easier to implement and at a lower cost when compared to traditional design methods. In other words, by promoting collaboration between actors in making important decisions and resolving complexities in the early phases, when changes are simpler and less costly, the project can be developed more efficiently, leading to lower modification costs and more effective management of sustainability criteria, budget, and schedule.

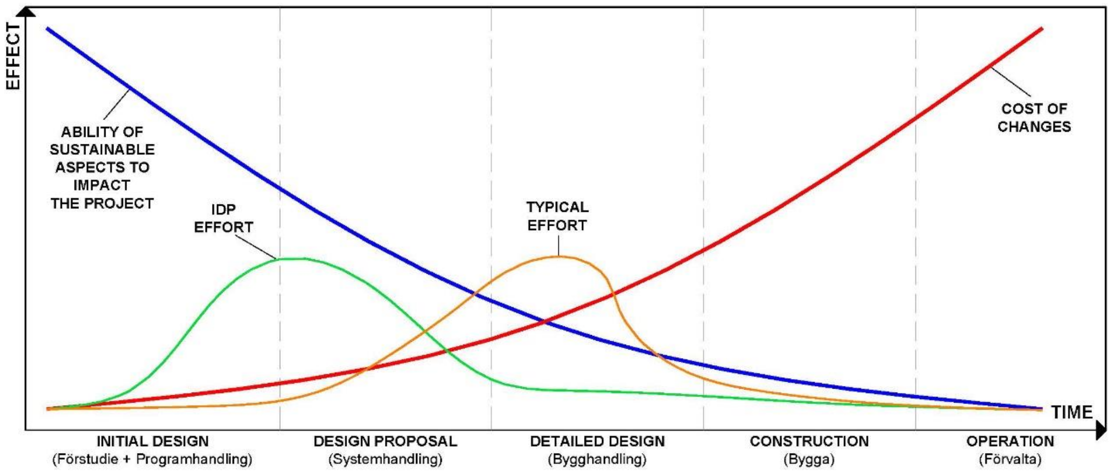

Figure 5: Time-effort distribution between early and late implementation of sustainable aspects, based on (CURT - The Construction Users Roundtable, 2004)

3.5. Basic Principles of MCDA

In analyses of complex decisions involving multiple criteria, it is advisable to adopt a structured approach that begins with a clear definition of the problem and organising the objectives. This structuring allows not only the identification, but also the efficient categorization of criteria, facilitating subsequent analysis. In decision-making it is necessary to make choices and trade-offs between different criteria using tools that evaluate these trade-offs rationally, but multi-criteria analysis deals with more complex and uncertain situations. As the number of criteria increases, so does the complexity of the decision, requiring more detailed approaches and consideration of long-term effects (Keeney & Raiffa, 1993). Aggregating individual preferences in collective contexts, such as in the construction sector, requires methods that can represent a consensus among stakeholders. Understanding and applying these concepts is crucial for effective decisions in multiple and contradictory criteria scenarios.

Multicriteria Decision Analysis (MCDA) is a methodology used to evaluate and support decisions by evaluating alternatives based on a set of criteria to determine the best possible decision according to the specific needs of the project in accordance with the available criteria (Raufaste & Hilton, 2009). This process is fundamental for dealing with complex decisions where multiple conflicting criteria need to be balanced, as highlighted by Kerzner (2023), who emphasizes the importance of confronting complex choices that cannot be resolved by considering a single factor. MCDA does not only analyse the problems, but also helps in the search for a trade-off when satisfying all the criteria proves to be impractical.

Bhuiyan & Hammad (2023) complement this view by defining MCDA as a systematic approach that generates alternative scenarios, establishes criteria, evaluates alternatives, and weighs the criteria. It highlights the importance of subjective (qualitative) and objective (quantitative) methods in criteria weighting techniques, which underlines the need for a balanced and informed approach to decision-making. Dodgson et al. (2009) expand the discussion by presenting MCDA as a means of aiding thinking and decision-making, where the aim is not only to make the decision, but also to provide a general ordering of the alternatives. This approach supports decision-makers in developing coherent preferences within the framework of the problem in question, emphasizing the importance of breaking down the problem into more manageable parts.

3.5.1. Multi Actor Multi Criteria Analysis (MAMCA)

The MCDA methodology does not take into considerations the objectives of different stakeholders to be included in the decision-making process, which is essential for the acceptance of the measures or projects considered (Macharis et al., 2010). In the context of group decisions, MAMCA involves capturing and prioritizing the multiple and subjective objectives of stakeholders, establishing a hierarchy of criteria or a criteria tree that expresses the values/objectives of stakeholders. This implies reaching a consensus despite potential divergent points of view, especially in complex problem settings where stakeholders' objectives are heterogeneous and conflicting (Baudry et al., 2018).

The main addition of the MAMCA methodology to the MCDA process is highlighted by this capacity for participation, allowing the voice of all relevant stakeholders to play an important role in the decision-making process (Heuninckx et al., 2024). which can be observed in the initial stages after structuring the problem definition and identifying the alternatives to be evaluated. At this stage, the relevant stakeholders involved in the decision-making process are mapped, followed by the establishment and prioritization of the relevant criteria for these parties. The criteria are then associated with specific indicators, whose measurement methods are set out, making it possible to assess the contribution of each alternative to the stakeholders' objectives (Macharis et al., 2012). After these stages, there is a better understanding and traceability of the different priorities of the stakeholders, contributing to the subsequent stages of evaluating the alternatives to mitigate conflicts in decision-making.

3.5.2. General Stages of the MCDA Process

The process of formulating an MCDA framework is divided into eight stages (figure 6). To obtain an effective result in the development of an MCDA, these steps must be understood and carried out in an integrated and systematic manner. Below are the steps as described by Dodgson et al. (2009):

Establishing the context of the decision: In the initial stage of the MCDA, the objectives are established, the key participants involved who may directly or indirectly influence or be affected by the decision-making process are identified, the socio-technical system that integrates the social (people, organizations, policies) and technical (tools, analysis methods) aspects needed to conduct the process is designed, and the context in which the decision will be made is assessed, including economic, political, social and environmental factors that may affect the alternatives and decision criteria.

Identify the alternatives to be evaluated: It is clearly stated what alternatives are available for decision-making. These can be strategies, projects, investments, policies, materials etc.

Identify objectives and criteria: Specific criteria are selected that will be used to evaluate and compare the alternatives. The criteria should be measurable and relevant to the decision objectives and should be organized and grouped in a hierarchical structure, such as decision trees, to simplify the analysis and ensure that all aspects of the decision are considered.

Scoring: A detailed description is drawn up of the potential impact of each alternative, evaluating them according to the established criteria, assigning a score that reflects the expected performance. Scores should be reviewed to ensure that they are consistent and balanced across all criteria and alternatives.

Weighting: A weight is assigned to each criterion, reflecting its relative importance in the analysis. This is essential to ensure that the most significant criteria have the greatest impact on the final decision.

Combining the scores and weights: Calculations are carried out to integrate the weights and scores at each level of the criteria hierarchy, where all the weighted scores are then combined to obtain an overall value for each alternative, facilitating direct comparison between them.

Examine the results: The aggregate values are analysed to understand the strengths and weaknesses of each alternative, allowing a clear view of which alternative offers the best balance between the different criteria.

Sensitivity analysis: The robustness of the results is tested by changing weights and criteria to check whether changes in parameters significantly affect the ranking of the alternatives, comparing them directly to identify competitive advantages or disadvantages. If necessary, additional alternatives are proposed that can resolve the deficiencies observed in the current alternatives and the process is repeated as necessary to refine the decision, ensuring that the final model is suitable for solving the problem in question.

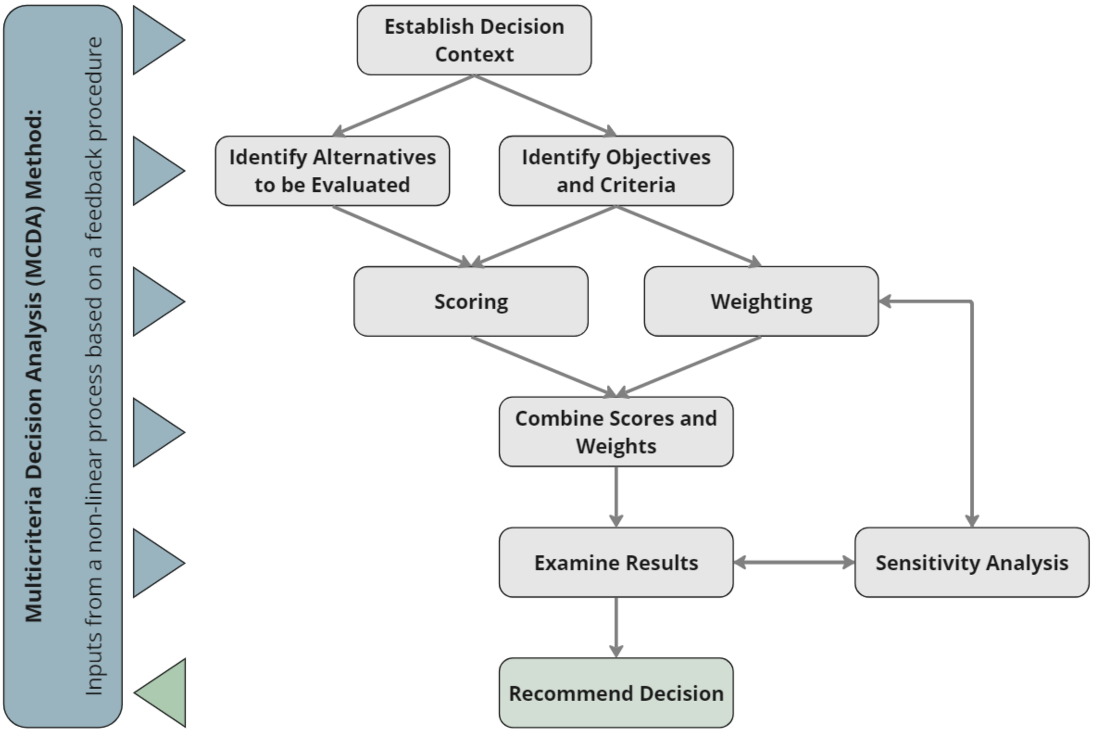

Figure 6: General stages of the MCDA process, based on (Desgain et al., 2015).

3.5.3. MCDA in the Construction Sector

The concept of multi-criteria decision analysis (MCDA) can be a useful tool in the context of construction, especially in the early stages of a project, when materials, techniques or technologies are chosen based on multiple criteria. During the selection of materials, for example, quantifiable criteria such as cost, durability and thermal insulation capacity are considered, along with qualitative aspects such as aesthetics and ease of installation. Decision-making in construction involves evaluating these various alternatives which often have conflicting properties, such as the search for high quality at low cost (Cho & Chae, 2022).

The evolution of the construction sector has led to an increase and diversification of criteria that present conflicts between stakeholders. Environmental and social aspects are increasingly important and their proper interaction with economic considerations is a relevant factor for the success of construction projects (Jato-Espino et al., 2014). Ek et al. (2019) argue that the use of MCDA in construction is suitable for the predictive evaluation of sustainability issues and has been used frequently for this purpose. Zhu et al. (2021) studied a total of 530 civil engineering construction articles published from

2000 to 2019 and complement that the use of MCDA enables a comprehensive assessment that simultaneously considers aspects such as cost, time, quality, sustainability, and risk, contributing to more informed and balanced decisions and being applied in a variety of project contexts.

Other aspects in which MCDA has been used in construction involve the selection of projects and the most suitable contractors and consultants for a given project. It is also used in the selection of materials to compare their durability, cost, and environmental impact in order to ensure issues of sustainability and technical suitability (Zhu et al., 2021). Through criteria analysis and scoring, MCDA models can integrate the preferences and contributions of all stakeholders, such as project owners, designers, and contractors, and can reflect the collective views of all those involved in the decision-making process (Bhuiyan & Hammad, 2023).

In risk management, MCDA helps assess and mitigate project risks by evaluating the impact of various factors on project objectives. Additionally, it assesses the sustainability performance of projects and supports resource allocation, optimizing the use of such resources as manpower and equipment for cost efficiency. Finally, MCDA also supports infrastructure planning by analysing design options and construction methods to select the best solutions that meet project requirements and stakeholder needs (Zhu et al., 2021).

However, the application of MCDA can present several challenges that can affect the effectiveness and efficiency of decision-making processes. Among the challenges is subjectivity and bias in the interpretation of criteria weights and preferences by decision-makers, which can introduce tendencies, compromising the objectivity and transparency of the process. Another significant problem is the availability and quality of data for evaluating criteria and alternatives, where inaccurate or incomplete data can lead to unreliable decision results. In addition, the scalability of MCDA in projects with many alternatives and criteria can make the process complex and intense, which can affect the reliability of the method. Finally, the involvement of stakeholders with different perspectives and priorities is also a difficult factor to handle, and it is necessary to balance conflicting interests and ensure effective communication and collaboration (Zhu et al., 2021).

There are several MCDA methods that offer varied approaches to help in solving complex problems, each adapted to different needs and decision-making contexts. As cited by Bhuiyan & Hammad (2023), among the various MCDA methodologies employed in the construction sector, the main techniques highlighted are SAW (Simple Additive Process), AHP (Analytic Hierarchy Process), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) and VIKOR (Visekriterijumska Optimizacija I kompromisno resenje, or Multicriteria Optimization and Trade-off Solution). These methods, by incorporating fuzzy theory to deal with uncertainties and imprecision, allow the identification of the most suitable options based on predefined criteria.

3.5.4. Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a methodology developed by Thomas L. Saaty and broadly used to support complex decision-making. Its theoretical foundation lies in the use of advanced mathematics to deal with multi-criteria decision problems. The technique uses matrices to organize and quantify decision criteria and alternatives (Dodgson et al., 2009). The AHP consists of two main phases. The first phase involves data collection, which is conducted through comparisons between pairs of criteria and sub-criteria (more detailed components within a specific criterion that support the analysis of broader topics into more manageable and precise elements), while the second phase comprises of executing the AHP method (Cabral & Blanchet, 2023). The following are the steps for executing the AHP method according to Saaty & Vargas (2012):

Decide the overall goal of the problem, alternatives, and structure of hierarchy

The stage of deciding the overall goal of the problem involves determining the main objective and building a hierarchical structure that adequately represents the decision-making context (figure 7). This structure should clearly present the overall objective, the criteria, and sub-criteria, as well as the alternatives considered, organized in a way that allows a visual overview of the complex relationships and an effective comparison between elements. It is crucial that the hierarchy is flexible, allowing for adjustments and refinements as necessary to focus on critical aspects of the problem and discard less impactful elements after assessing their influence on the overall objective.

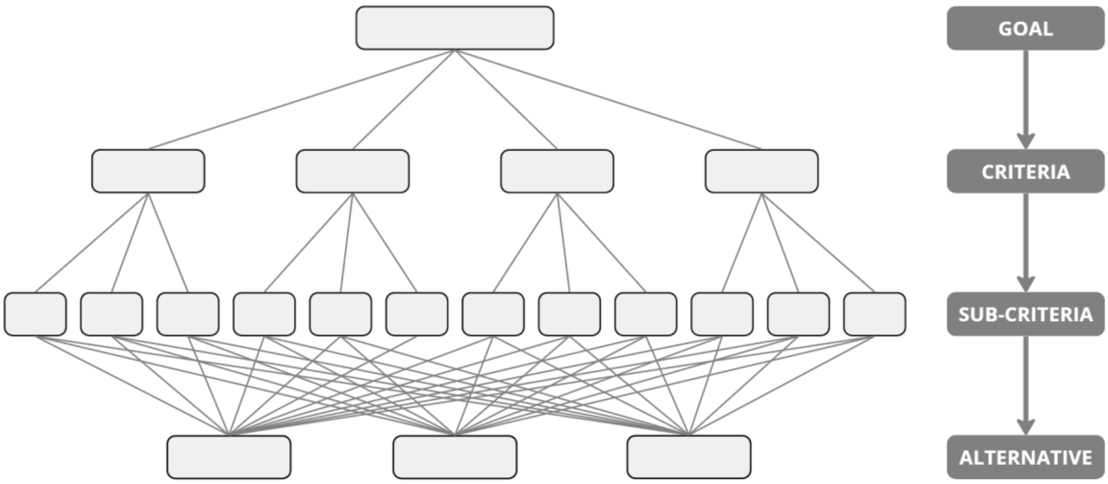

Figure 7: Hierarchical structure of decision-making, based on (Saaty & Vargas, 2012)

Pair-wise Comparison

Pair-wise comparison is a technique that allows decision-makers to structure complexities of multi-criteria decisions in a hierarchical and quantifiable way. This step assumes that although decision-makers may have difficulty evaluating complex options in an absolute way, they are able to make more reliable judgments in a relative way, that is, by comparing pairs of options.

Once the criteria have been defined, it is necessary to measure the relevance of one criterion in relation to another, a process that is carried out by means of systematic paired comparisons. In each comparison, one criterion is compared to another, and the decision-maker has the task of assigning a value that quantifies the degree of preference of one over the other, based on a numerical scale of judgment intensities that allows these preferences to be represented. Table 2 represents the fundamental scale of pair-wise comparison proposed by (Saaty T. , 2008).

Table 2: AHP Pair-wise Comparison Scale Definitions and Explanations.

Weight	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective.
3	Moderate Importance	One activity is slightly favour over another.
5	Strong Importance	One activity is strongly favour over another.
7	Very Strong	One activity is very strongly favour over another.
9	Extreme Importance	One activity is overwhelmingly favoured over another.

Conduct Pairwise Comparison matrix

When carrying out pairwise comparisons on a set of n criteria, a matrix A of size $(n \times n)$ is produced, in which each element a_{ij} $(i, j = 1, 2, \ldots, n)$ represents the relative importance of criterion i in relation to criterion j. According to the relationship $a_{ij} = {}^{a}/_{a_{ij}}$ $for\ i \neq j$, the elements outside the main diagonal are the inverse of each other, and the elements on the main diagonal, where $i = j$, are always equal to 1, reflecting the equal importance of a criterion compared to itself. This configuration establishes a reciprocal matrix for paired comparisons A which can be formalized mathematically in the following expression:

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix}, a_{ij} = \frac{1}{a_{ji}}, a_{ji} \neq 0 \qquad (\mathbf{1})$$

Conduct Normalized matrix

The elements in each column of the paired comparison matrix must be summed together. This serves as a preparation for the subsequent normalization of each element of the matrix. For each column j of matrix A, the sum is calculated by adding up all the values a_{kj} in the column in question, where k represents the number of criteria or alternatives. This sum S_j will be used as the denominator in the matrix normalization process. Mathematically, this is represented by the formula:

$$S_J = \sum_{k=1}^{n} a_{kj} \qquad (\mathbf{2})$$

After calculating the sums of the columns, each element of matrix A is divided by the sum of the corresponding column. This results in the normalized matrix A', where each normalized element a'_{ij} is calculated as:

$$a'_{ij} = \frac{a_{ij}}{S_j} \qquad (\mathbf{3})$$

The result is the matrix A' expressed as:

$$A' = \begin{bmatrix} 1 & a'_{12} & \cdots & a'_{1n} \\ a'_{21} & 1 & & a'_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a'_{n1} & a'_{n2} & \cdots & 1 \end{bmatrix} \qquad (\mathbf{4})$$

Measure Weights

To determine the relative weights of each criterion, the average of the elements in each row of the normalized matrix is calculated. These average values represent the W_i weights of each criterion and are calculated as:

$$W_i = \frac{1}{n}\sum_{j=1}^{n} a'_{ij} \qquad (\mathbf{5})$$

Consistency Check

The Consistency Check is a verification procedure that assesses whether the pairwise comparisons made between the elements are logically consistent. In other words, it is a test to ensure that the preferences or judgments expressed in the pairwise comparison matrix are not contradictory and follow an appropriate proportional relationship.

In this way, is necessary to compute the matrix X, which represents an n-dimensional column vector that aggregates the weighted values corresponding to the degrees of importance. This is achieved through the calculation X = A x W, where:

$$X = A \times W \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \times \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_n \end{bmatrix} \qquad (\mathbf{6})$$

$c_i(j = 1, 2, \ldots, n)$ is the vector of wights value of criteria.

Following is necessary to stablish the individual value of each vector. This value is calculated by dividing the vector of wights value of criteria by the weights determined for each criterion:

$$\begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_n \end{bmatrix} = \begin{bmatrix} c_1/W_1 \\ c_2/W_2 \\ \vdots \\ c_n/W_n \end{bmatrix} \qquad (\mathbf{7})$$

The next step is to determine Consistency Index (CI) which measure of how consistent the pairwise comparisons are within the comparison matrix. As lower the CI, more consistency is the evaluations. The CI is represented as follow:

$$CI = \left(\frac{\lambda_{avg} - n}{n - 1}\right) \qquad (\mathbf{8})$$

Where:

$$\lambda_{avg} = \left(\frac{\sum \lambda_i}{n}\right) \qquad (\mathbf{9})$$

Finally, to validate the results of the AHP, the consistency ratio (CR) is calculated. A CR value smaller than 0.1 is considered acceptable and consistent, confirming the reliability of the results.

$$CR = \left(\frac{CI}{RI}\right) \qquad (\mathbf{10})$$

Where the average random consistency index (RI) is present as following:

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,52	0,89	1,11	1,25	1,35	1,40	1,45	1,49

3.5.5. Simple Additive Weighting

The Simple Additive Weighting (SAW) method, also known as the weighted sum model, is widely used and straightforward decision-making technique (Podvezko, 2011). The SAW method uses the process of multi-attribute value, which represents a function that is established based on a simple addition of scores that represent the goal achievement under each criterion, multiplied by the weights (Qin et al., 2008). This process integrates the scores of the criteria and their respective weights into a single, comprehensive value, thereby determining the rank of each alternative. The weighted sum of the performance ratings is calculated by multiplying each criterion's score by its assigned weight, reflecting the criterion's relative importance.

The basis is to calculate the weighted sum of the performance ratings. This should be calculated for each alternative/object on all attributes/criteria. The process should consider the weight of attributes, and the normalization of values ensures a dimension-free rating for the attributes in the method (Taherdoost, 2023). While the SAW method primarily focuses on maximizing evaluation criteria, it can also handle minimizing criteria by converting them into maximizing ones using specific formulas (Podvezko, 2011). These minimizing and maximizing evaluation criteria are often referred to as criteria of costs and benefits, respectively (Taherdoost, 2023). The following are the steps for executing the SAW method according to Taherdoost (2023):

Define the Alternatives and Criteria

The first step is to define the alternatives and criteria that will be used to evaluate the established decision context.

Identify the criteria C_i $(i, j = 1, 2, \dots, m)$ that will be used to evaluate the alternatives.

List all the alternatives A_j $(i, j = 1, 2, \dots, n)$ that are being considered.

Assign Weights to the Criteria

Determine the importance of each criterion and assign a weight to each one. The sum of all weights should equal 1. This can be done using various methods, such as expert judgment, scale 0-100, or pairwise comparison.

$$\sum_{i=1}^{m} w_i = 1 \qquad \mathbf{(1)}$$

Construct the Decision Matrix

Create a matrix X of size $(m \times n)$ where each row represents an alternative and each column represents a criterion. The values in the matrix represent the performance of each alternative with respect to each criterion. This configuration establishes matrix X which can be formalized mathematically in the following expression:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \qquad \mathbf{(2)}$$

Normalize the Decision Matrix

Normalize the values r_{ij} of alternatives A_j according to the criterion C_i in the decision matrix to make them comparable. This value must be calculated in this step considering whether the problem is a cost or benefit type. The difference is that in the lower value the object is minimizing, on the other hand maximizing is the object of a higher value. These differences reflect in the r_{ij} calculation as follows:

$$r_{ij} = \frac{\min(x_{ij})}{x_{ij}} \qquad \textbf{(3)}$$

If j is a minimizing attribute (lower is better)

$$r_{ij} = \frac{x_{ij}}{\max(x_{ij})} \qquad \textbf{(4)}$$

If j is a maximizing attribute (higher is better).

After normalization of values, the normalized decision matrix R is obtained where each element r_{ij} represents the normalized value of x_{ij}.

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \qquad \textbf{(5)}$$

Calculate the Weighted Sum

Multiply the normalized values by the corresponding weights and sum them up for each alternative. Calculate the weighted sum S_i for each alternative A_i using the formula:

$$S_j = \sum_{i=1}^{m} w_i \times r_{ij} \qquad \textbf{(6)}$$

Rank the Alternatives

Rank the alternatives based on their weighted sum scores S_j. The alternative with the highest score is considered the preferred option represented by the formula:

Rank (A_j) = Order of S_J in descending order.

3.5.6. Sensitivity Analysis Approach for MCDA Methods

The sensitivity analysis is a process used to evaluate how variations in the weights of the decision criteria influence the ranking of the MCDA. When focusing on the decision criteria weights the goal is to examine the robustness of each criterion by determining the smallest change in criteria weights that can alter the existing ranking of alternatives (Triantaphyllou, 2013). The steps for carrying out a sensitivity analysis are as follows:

Determine the minimum change in criteria

The first step is to determine the smallest change in the weights of the criteria that can modify the existing ranking of the alternatives. To do this, it is necessary to find the value of Δ (Delta). Δ represents the minimum change in the current weight of criterion C_k so that the ranking of alternatives A_i and A_j is inverted and is represented as $\Delta_{k,i,j}$.

Calculating the Delta value

On the next step, all possible combinations of criteria and alternatives must be identified. For each combination, the value of Δ is calculated using the following formula:

$$\Delta_{k,i,j} = \frac{P_j - P_i}{a_{jk} - a_{ik}} \qquad \mathbf{(1)}$$

Where P_i and P_j are the values of the weighted sum of alternatives A_i and A_j, while a_{ik} and a_{jk} are the scores of alternatives A_i and A_j on criterion C_k.

Check the feasibility of Delta

Check whether the Δ value is less than the current weight of the W_k criterion. If it is, the Δ value is feasible; otherwise, the value is not feasible (N/F).

$$W_k \geq \frac{P_j - P_i}{a_{jk} - a_{ik}} \qquad \mathbf{(2)}$$

Where W_k is the current weight of criterion C_k

Calculate the Delta line value

Δ' represents the percentage change in the weight of the criterion required to change the ranking of the alternatives. The Δ' value is calculated using the formula:

$$\Delta' = \frac{\Delta \times 100}{W_k} \qquad \mathbf{(3)}$$

Analysing the results

The next stage involves analysing the Δ' values to determine which changes in the criteria weights affect the ranking. Negative values indicate that the weight should be increased to reverse the ranking, while positive values indicate that the weight should be reduced.

Identifying the Most Critical Criteria

In the last stage, the lowest Δ' values in the results table are identified. This value indicates the most critical criteria, as a lower change in these criteria weight can alter the ranking of the alternatives, influencing the recommended decision.

3.6. Leveraging Literature for Research Design and Data Collection

The literature review focused on understanding the concept of Multi-criteria Decision Analysis (MCDA) and how it can be applied specifically in the context of the construction sector. This approach allowed the formation of a theoretical basis for the thesis, identifying topics such as the importance of decision-making in construction projects and the main challenges that influence this process, the complexity of projects, stakeholder management and how they evaluate and prioritize different criteria. Thus, capturing a holistic view of the decision-making process in construction projects.

By examining the existing literature, this chapter has identified areas that guide the subsequent interview and questionnaire stages presented in this study. The identified themes of project complexity, stakeholder management and multicriteria decision-making, guiding the formulation of interview questions, with the aim of discovering how stakeholder views and criteria influence project decisions, delving into the dynamics of decision-making processes, the importance of various decision criteria and the roles of the different actors.

Similarly, the results obtained in the literature review served as the basis for formulating the questionnaire, which identified broader criteria to be considered in the project decision-making process, in addition to the engagement of the stakeholders involved. The literature review also sought to analyse which Multicriteria Decision Analysis methodologies would best suit the development of this study, reflecting in the structuring of the questions developed for the questionnaire to obtain the data that could be applied to the selected techniques.

CHAPTER 4

RESULTS

SUMMARY

This chapter presents the results from stakeholder interviews and questionnaire, followed by the development and application of an MCDA prototype. It begins with interview results, highlighting stakeholders' perspectives, understanding of project goals, and decision-making dynamics. The next section quantifies and analyses questionnaire results, identifying key actors and their relationships. The final section details the MCDA prototype's development and findings, including scenario-based evaluations and sensitivity analyses, showing how varying factors and stakeholder influences impact decision outcomes.

4.1. Interview Results: Decision-making in the Case Project

The interviews were a method used to understand the complex interplay of stakeholders in the decision-making process in the case study. The gathered interview data from several stakeholders connected to the project reveals a landscape of collaborations, influences, and perspectives. From the beginning, it was clear that the stakeholders were generally satisfied with the project´s decision process, which made the interviews particularly intriguing to understand the reasons behind this satisfaction. During the interviews, several recurring themes emerged, including the identification of clear project goals, the decision-making process, and collaboration among stakeholders.

4.1.1. Clear Project Goals

The interviews revealed that the participants universally acknowledged that the project has ambitious sustainability targets. As one of the interviewees highlighted:

> *"The Client had this idea for the project to have a 50% reduce in carbon emissions during its lifetime, so it has been quite challenging actually to help them create the product that is so efficient, and I guess that has also been the driving factor for this project."* – Business Manager

Despite these high ambitions, several stakeholders mentioned the challenge with economic constrain. The need to balance costs associated with sustainable innovation present challenges. As one interviewee noted,

> *"Money talks, and while we aim for reducing the CO2 emissions as much as possible, some economic realities cannot be ignored. In projects you always have time, quality, and money, that's always in consideration, but then we had a fourth parametric of CO2 and that was a huge one that would triumph all the others."*
> – Project manager

Participants also discussed how decisions are made, considering the environmental impact and cost. One interviewee explained their approach to evaluating decision alternatives.

> *"We do a climate calculation to see where the big climate impacts are and then develop alternative ways of constructing. Should we have a framework in wood or concrete and it's a very big difference in climate impact. We present the calculated climate impact analysis with a cost analysis to showcase how the alternatives would differentiate. What would be the climate impact and how large are the cost per tonne CO2?"* – Environmental specialist

It was explained by several interviewees that having these clear goals made the decision-making process easier because it, in general, was clear what the priorities were and how to align various factors of the project towards achieving these targets. This clarity provided strong direction and it streamlined decision-making, making it easier to justify choices that might have seemed costly but were necessary for sustainability. Additionally, this clear focus fostered a sense of collective responsibility and commitment among stakeholders, creating a shared sense of purpose.

4.1.2. Overview of Decision-Making Processes

Interviews with the participants of the case project revealed a consensus that the Client holds the primary decision-making power. Most interviewees acknowledged the Client's final say in the decision process, emphasizing the complexity and collaborative nature of these decisions. The Business Manager pointed out the collaborative dynamics involved, stating:

> *"There was a co-creation process between us, because it requires something from everyone involved because in a lot of these decisions. Input is required from other people, of course we can suggest things, but in the end it's up to the Client to make the decision."* – Business manager

An Environmental Specialist highlighted the technical influence of other roles and the ultimate power of the Client:

> *"I think as a specialist in this field or any other field you have the power to know your thing and it's quite difficult for anyone else to say, no, that's not working… I would say we as the engineers have a lot of impacts on how the technical aspects will look and will be used in the project and work as advisors, but it's always like the property owner or the customer who takes the loss and by that the power of saying yes or no."* – Environmental specialist

These statements underline the structured yet complex nature of decision-making within the project, where the Client's authority is definitive yet informed and influenced by the expert contributions from various stakeholders.

4.1.3. Collaborative Decision Process and Use of Decision-Making Tools

The project´s success in stakeholder collaboration is evident in the interactions described by various interviewees. The project manager emphasises the importance of project studio as a crucial part of the process as it allows for real-time involvement, ensuring that decisions can be discussed in persons. Minimising miscommunications, and thus conflicts. The Client agrees with this and adds that:

> *"It's better to be as open as possible with each other and work together. Especially in a project like this that are full of uncertainties."* – Client

Several interviewees agreed that the implementation of the "Project Studio" model played a crucial role in fostering real-time collaboration and decision-making among the project's stakeholders. This innovative approach involved co-locating all key participants architects, engineers, and project managers in a single workspace with meetings and discussions. This setup facilitated immediate access to relevant data and experts, significantly reducing the time typically consumed by traditional communication methods.

Identified Criteria and Sub-criteria

The second part of having the interviews was to identify the sub-criteria considered by the interviewees. As seen in figure 8, the stakeholders range from various roles, each and everyone connected to the case study project. These sub-criteria have been categorized into suitable themes, which are named as criteria. The criteria themes identified are as follows: Environmental, Economic, Social, and technical factors.

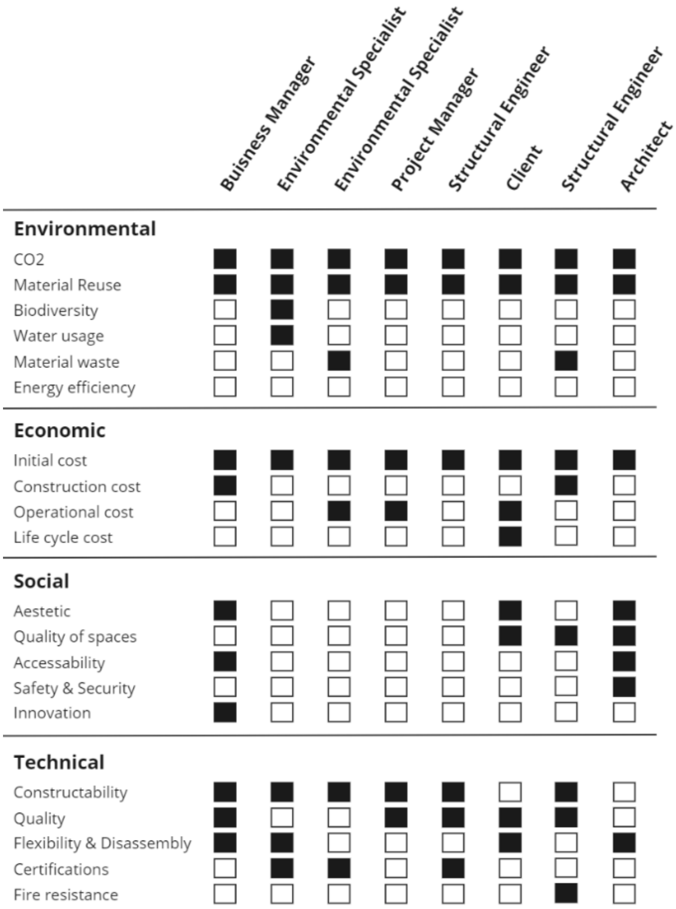

Figure 8: Identification of sub-criteria discussed by the stakeholders in the case project, separated in themes of criteria: environmental, economic, social, and technical criteria.

In the interviews, when asked about what the respondents considered as important in the project, there were recurring points made by all stakeholders, that certain sub-criteria, the CO2 emissions, the material reuse, and the initial cost are of universal concern. This indicates a consensus on the importance of these criteria. This is in line with the general project goals of wanting to reduce the CO2 emissions by 50 % with the lowest cost possible. Based on the findings in table 4, a pair-wise approach was used to identify how the stakeholders would prioritise the criteria when they are evaluated against each other.

4.2. Questionnaire Results

The questionnaire was a method used to quantify the subjective thoughts and point of views of the interviewed stakeholders. It gave the thesis a way to convert qualitative data to quantitative data, which then could be used to build and complete the MCDA prototype.

4.2.1. Prioritised Criteria

One important step in the questionnaire was to reduce the list of sub-criteria to a more manageable amount for this study. Figure 9 illustrates the stakeholder's criteria prioritization, in which it displays that Economic and Environmental criterion being most important, with technical criteria being somewhat important and social criteria considered the least important. This evaluation of priorities helped streamline the study by focusing on a more manageable number of sub-criteria for the final MCDA prototype. Concentrating on the most critical factors, Economic and Environmental. This limitation ensured the prototype addressed the key concerns identified by the stakeholders, enhancing its relevance and practicality in application.

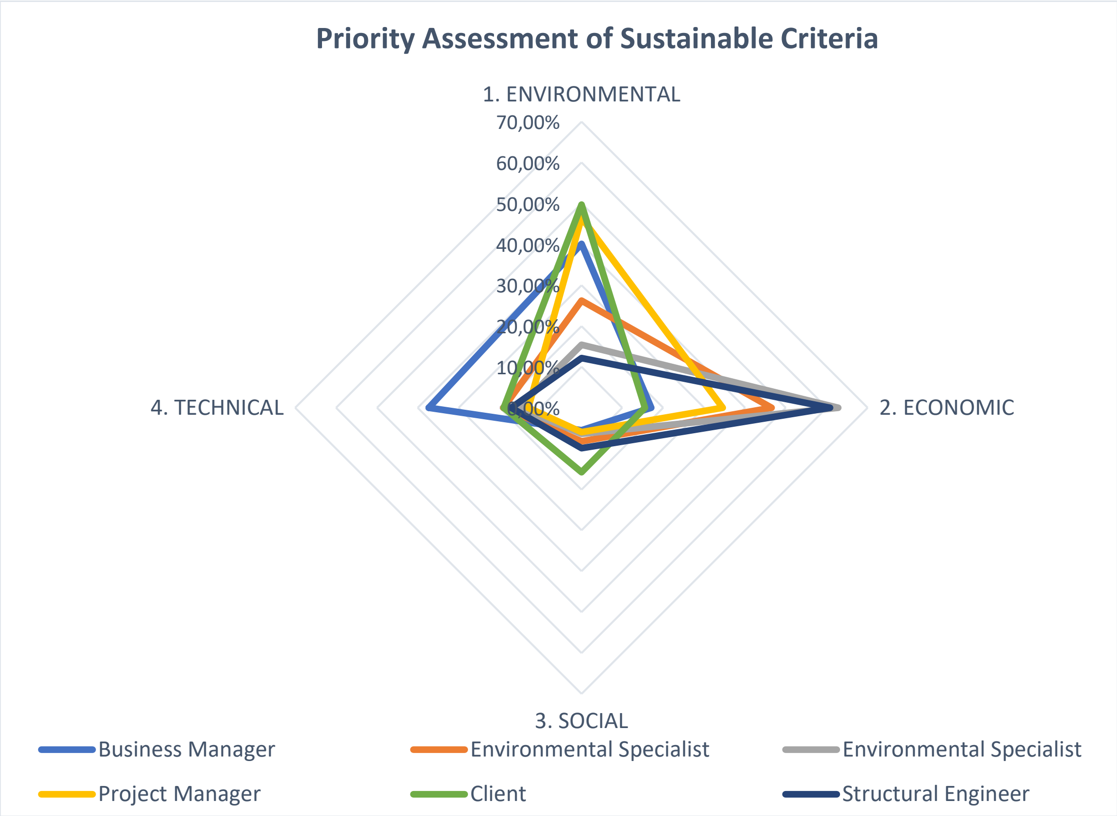

Figure 9: Priority Assessment of Sustainable Criteria among Different Stakeholders

4.2.2. Power-Interest Matrix

To categorise and analyse the involvement of stakeholders in the decision of the cladding system, a power / interest matrix was developed. This matrix makes it possible to visualise the level of involvement of each stakeholder in each project activity. Based on the results obtained from the questionnaire, it was possible to classify which stakeholders had the most power in the decision-making process, and which were directly involved in the decision of the external cladding.

As shown in figure 10 the Client, Project Manager and Architect were the Key Players in the choice of external cladding, with the Client having the greatest decision-making power and the highest level of interest. Both the Environmental Specialist and the Technical Consultant do not have direct decision-making power; thus, they are placed in the “Keep informed” quadrant. However, they are directly involved in the choice of cladding system. The Regulatory Agencies have a high level of influence in decision-making but have a low level of involvement in the selection of the external cladding making the placement in the “Keep satisfied” quadrant obvious. The other stakeholders are actors placed in the monitored quadrant as they have no decision-making power and were neither actively involved in the cladding decision.

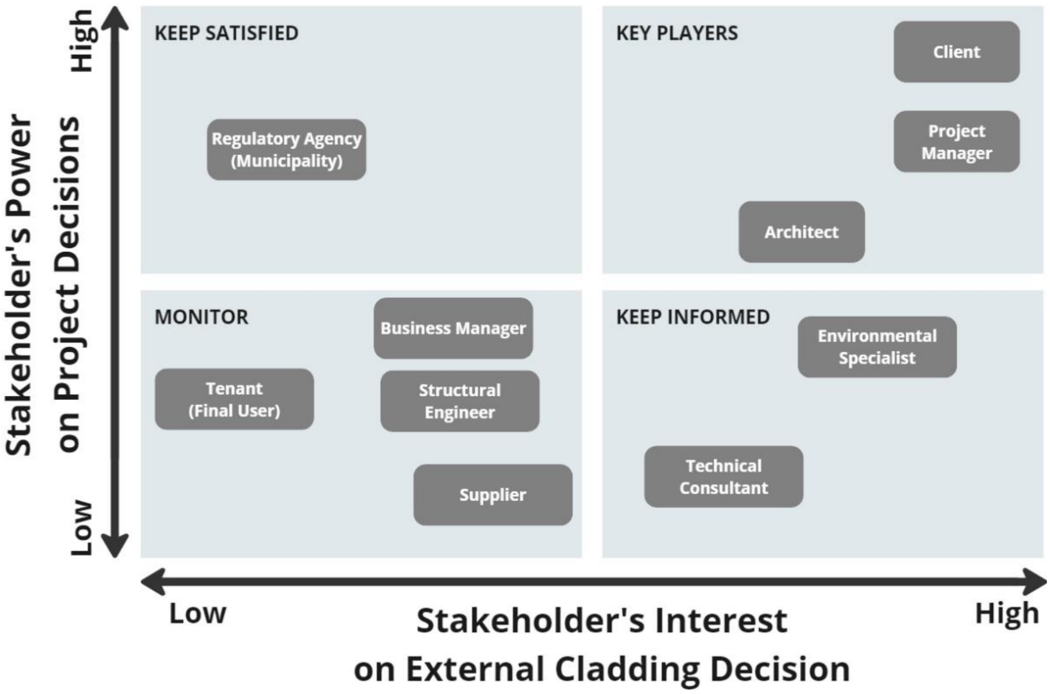

Figure 10: Power/Interest Matrix, visualising each stakeholder on the spectrum of their power and interest on deciding the cladding system.

4.2.3. Multi-Actor Network

Based on figure 10, an analysis was carried out to understand the complexity of the interactions and mutual influence between the stakeholders. Data was collected through the questionnaire. The participants answered questions about the frequency of their interactions with other stakeholders in the project. Figure 11 looks deeper at the influence of these actors in the project's decision-making, where the size of the nodes reflects the influence of each stakeholder, with the biggest nodes representing the most influential players. The second thing figure 11 highlights is how information and decisions flow predominantly to and from these actors, where the different lines illustrate the amount of communication stakeholders has with each other.

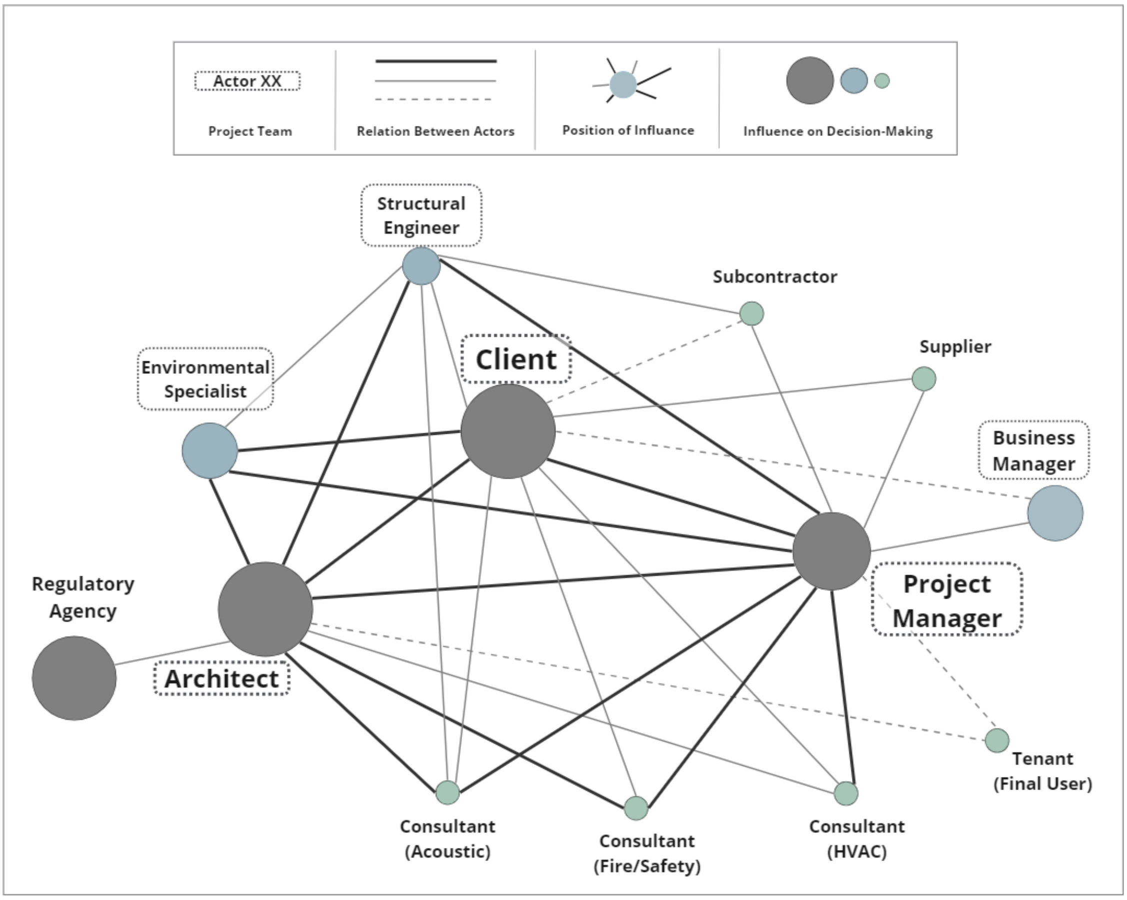

Figure 11: Social Network graph illustrating the stakeholders influence on decisions and interactions with each other.

4.3. Building an MCDA Prototype to Support Decision-Making

This section presents the prototype developed based on the case study and follows the general stages of an MCDA: establishing the decision context, identifying alternatives, scoring, and weighting criteria, combining scores and weights, making the recommended decision, and conducting a sensitivity analysis.

4.3.1. Establishing the Decision Context

Several interviews highlighted one activity discussed more extensively than others in the case project: the decision regarding external cladding. This subchapter will use the MCDA methodology to replicate the project's decision-making process, exploring whether the same decision would be reached under different circumstances and assessing the impact of varying parameters within the MCDA. Would the outcome remain consistent with the original decision, or would changing certain parameters lead to a different choice? The interviews also revealed that the Client often had the final say. Therefore, this prototype will only consider the Client's weight and perspective.

4.3.2. Identifying the Alternatives

Documentation received from the partnering organisation gave our study the possibility to evaluate the same alternatives as in the studied case project. Presented in Table 3, three of the alternatives were considered: a concrete cladding alternative, a timber alternative, and a steel cladding alternative. It should be noted that the concrete cladding uses traditional concrete (not carbon neutral), the timber is sourced from Sweden, and the steel cladding is normal steel that is not based on recycling. Because of confidentiality, the real values are hidden, but the normalisation indicates the differences of each alternative´s values in comparison to each other.

Table 3: Selected cladding alternatives with CO2 emissions and cost comparisons.

Alternatives	**CO2 Emissions** (Normalized value)	**Cost** (Normalized value)
Concrete Cladding	0,48	0,39
Timber Cladding	0,14	0,29
Steel Cladding	0,38	0,32

4.3.3. Final List of Sub-criteria for the Cladding Decision

For the proposed prototype simulation, supplementary criteria were added that could influence the specific decision of a particular external cladding system. The selection of these additional criteria was based on the topics discussed during the interviews with the stakeholders, as well as the results obtained in the questionnaire. Based on this, the final selection of sub-criteria for the MCDA prototype are *CO2 Emissions, Potential for Recycling, Cost, Availability, Weight*, and *Operational Life.*

4.3.4. Scoring

Each alternative needs to be evaluated based on the identified sub-criteria and be given a score. Table 4 describes how the values of each sub-criteria were obtained and from which source.

Table 4: Description of how sub-criteria are evaluated, and source provided the data.

Criteria Name	**Evaluation Specification**	**Data Source**
CO2 Emission	kg CO2e/m²	Provided by the partnering organization.
Cost	SEK/m²	Provided by the partnering organization.
Potential for Recycling	Average %	Derived from the book “Manual of Recycling: Buildings as Sources of Materials” by Hillebrandt et al. (2019).
Availability	Point system based on the geographical import location (Sweden = 1; Nordic = 2; Europe = 3; World = 4)	Stipulated according to data found in the Climate Database from Boverket.
Weight	Kilograms	Defined according to descriptions provided by material suppliers.
Operational Life	Number of Years	Derived from the book “Manual of Recycling: Buildings as Sources of Materials” by Hillebrandt et al. (2019).

CO2 Emission and Construction Unit Price were provided by the partnering organisation who collaborated with this thesis and carried out the studies for the different options in the case study; Potential for Recycling and Operational Life were obtained from an table presented in the book "Manual of Recycling: Buildings as Sources of Materials" written by Hillebrandt et al. (2019); Availability of material was stipulated according to geographical import location data found in the Climate Database from Boverket; and Weight was obtained according to material suppliers descriptions. Because of confidentiality with the partnering organisation, there data cannot be presented. Thus, figure 12 illustrates the normalised values to guarantee the confidentiality. All data are then normalised for the simplicity of presenting and evaluating.

	NORMALIZED INDICATORS					
ALTERNATIVES	CO2 Emission	Potential for Recycling	Cost	Availability	Weight	Operational Life
Timber Cladding	0,14	0,22	0,29	0,17	0,42	0,25
Concrete Cladding	0,48	0,27	0,39	0,33	0,45	0,43
Steel Cladding	0,38	0,51	0,32	0,50	0,13	0,32

Figure 12: Illustration of the normalized values of each sub-criteria in reference to its alternative.

4.3.5. Weighting

To weight the importance of the sub-criteria for the cladding decision, the SAW method was utilized. This approach makes it possible to transform the stakeholders' qualitative judgments into quantitative results using a numerical scale, which makes it easier to aggregate and analyse the results obtained in figure 13. This evaluation process creates a record of how the different actors evaluated the sub-criteria, allowing for traceability and transparency in the results presented.

CRITERIA WEIGHT EVALUATION - CLADDING SELECTION							
		CO2 Emission	Potential for Recycling	Cost	Availability	Weight	Operational Life
STAKEHOLDER ANALYSIS	Buisness Manager	25%	5%	25%	13%	12%	20%
	Env. Specialist	66%	34%	0%	0%	0%	0%
	Env. Specialist	25%	9%	22%	12%	14%	17%
	Project Manager	26%	5%	26%	18%	0%	26%
	Client	21%	17%	17%	17%	13%	16%
	Structural engineer	21%	5%	21%	21%	10%	21%
	Architect	20%	18%	15%	18%	15%	13%

Figure 13: Each stakeholder's weight distribution of the sub-criteria.

4.3.6. Combining the Scores and Weights

As mentioned in 4.2.1, Client is considered the final decider. Therefore, only the Client's weight will be accounted for and presented in the final decision analysis.

The combination of the weight and score then gives the finalised prioritisation of each alternative seen in figure 14. Each criterion, for each of the alternatives are summed to an average score. The alternative with the highest score is regarded to be the recommended decision.

		DECISION GROUP - Client						
	WEIGHT	21 %	17 %	17 %	17 %	13 %	16 %	
		CO2 emissions	Potential for recycling	Cost	Availability	Weight	Operational life	AVERAGE
ALTERNATIVES	Timber Cladding	0,21	0,07	0,17	0,17	0,04	0,09	**0,75**
	Concrete Cladding	0,06	0,09	0,12	0,08	0,04	0,16	**0,55**
	Steel Cladding	0,08	0,17	0,15	0,06	0,13	0,12	**0,70**

Figure 14: Comparison of three cladding alternatives based on the Client's weighted criteria.

4.3.7. Recommended Decision

The results shown in figure 15 illustrates that according to the weights assigned by the Client, the timber cladding ranks the highest, making it the preferred choice. This is followed by the steel cladding, and then the concrete cladding.

		DECISION GROUP - Client							
	WEIGHT	21 %	17 %	17 %	17 %	13 %	16 %		
		CO2 emissions	Potential for recycling	Cost	Availability	Weight	Operational life	AVERAGE	
ALTERNATIVES	Timber Cladding	0,21	0,07	0,17	0,17	0,04	0,09	**0,75**	1
	Concrete Cladding	0,06	0,09	0,12	0,08	0,04	0,16	**0,55**	3
	Steel Cladding	0,08	0,17	0,15	0,06	0,13	0,12	**0,70**	2

Figure 15: MCDA analysis considering only the Client´s perspective.

4.3.8. Sensitivity Analysis

The sensitivity analysis in figure 16 illustrates how variations in the weights assigned to different criteria affect the recommended decision Each criterion has a specific weight (percentage) reflecting its importance in the decision.

	WEIGHT	21 %	17 %	17 %	17 %	13 %	16 %
		CO2 emissions	Potential for recycling	Cost	Availability	Weight	Operational life
PAIR OF ALTERNATIVE	Timber / Concrete	N/F	Increase by 226 %	N/F	N/F	N/F	Increase by 48 %
	Timber / Steel	Decrease by 8 %	Increase by 9 %	N/F	Decrease by 7 %	Increase by 7 %	Increase by 29 %
	Steel / Concrete	N/F	N/F	N/F	Increase by 99 %	N/F	Increase by 61 %

Figure 16: Sensitivity Analysis of MCDA criteria weight.

The sensitivity analysis shows how the alteration in weight results in a change of decision between the alternatives. With some criteria more sensitive than others. For example, for the recommended decision to change from Timber to steel, based on the CO2 emission criteria, the weight would need to be decrease by 8 per cent. Thus from 21% to 13%. This means that the CO2 criteria is quite sensitive to change. The timber-steel pair illustrates low percentage differences for almost all criteria for a change in the recommended decision. Meaning that even small changes in the weight of these criteria can lead to a different recommended decision between Timber and Steel. This highlights the sensitivity of the decision-making process to these criteria and suggests that stakeholders need to carefully consider the weights assigned to each criterion to ensure a balanced and well-informed decision.

In contrast, the Timber/Concrete and Steel/Concrete pairs show that certain criteria, such as potential to recycling (increase with 226% between Timber and Concrete) and Operational life (increase with 61% between Steel and Concrete), are less sensitive, indicating that these decisions are more robust to changes in these criteria weights. This underscores the importance of understanding the varying levels of sensitivity among different criteria to make informed and resilient decisions in construction projects. On the other hand, cost criteria indicate Non-Feasible (N/F) for all alternatives, meaning that no matter the change in weight, the recommended decision will not change.

Overall, this sensitivity analysis demonstrates that while some criteria weights significantly impact decision outcomes, others remain Non-Feasible (NF) regardless of weight alterations. This analysis helps to identify which criteria are critical in the decision-making process and which are less impactful, providing valuable insights for optimizing the MCDA in construction project evaluations.

4.3.9. Multi-Actor Impact on the Cladding Decision

Evaluating stakeholder influence in Multi-actor Multi-Criteria Decision Analysis (MAMCDA) is crucial for making robust and balanced decisions. Different stakeholders often have varying priorities and values. By considering these diverse perspectives, MAMCDA ensures that the decision is not one-dimensional but rather reflects a comprehensive analysis that incorporates all possible perspectives and priorities. As shown in figure 8 (list of identified criteria), not all stakeholders have the same criteria prioritization in the project. Would the cladding decision change if different stakeholders were included in the decision.

Two different analyses were proposed here based on the Power/Interest matrix in figure 10. One where only the key players influence on the cladding decision, the other analysis considers if all stakeholders would have influence on the decision. These two multi-actor arrangements directly influence the importance of each criterion, assigning a different weight to each criterion based on the average preferences of the actors presented in each decision group. This could later be compared with the Client’s decision and see how the decision would differentiate. The two arrangements for this scenario are as follows:

- **DECISION GROUP – Key Players**: This group includes the Key Players, being the Client, Project Manager, and Architect, all of whom have high power and high interest in the decision-making process.
- **DECISION GROUP – All stakeholders**: This group comprises all stakeholders, with varying levels of power and interest in the decision-making process.

DECISION GROUP Analysis – Key Players

Based on the average weight established by the Client, project manager and architect (see figure 13 for detailed weight distribution of each actor). The results showed (figure 17) that on an overall performance, the timber cladding has the highest score, and therefore is the preferred decision. The steel cladding comes in second and the concrete cladding was ranked third. CO2 emissions was considered the most prioritized criteria with cost, operational life, and availability not far behind (in that order).

DECISION GROUP - Key Players								
AVERAGE WEIGHT	22 %	13%	19%	18%	10%	18%		
ALTERNATIVES	CO2 emissions	Potential for recycling	Cost	Availability	Weight	Operational life	AVERAGE	
Timber Cladding	0,22	0,06	0,19	0,18	0,03	0,11	**0,78**	1
Concrete Cladding	0,06	0,07	0,14	0,09	0,03	0,18	**0,57**	3
Steel Cladding	0,08	0,13	0,18	0,06	0,10	0,14	**0,68**	2

Figure 17: MCDA analysis considering the Client´s, Project manager´s & Architect´s perspectives.

DECISION GROUP Analysis – All stakeholders

When all stakeholders are considered, the collective average weights and preferences show that the timber partition wall is deemed the preferred alternative, see figure 18. The steel cladding alternative a close second and the concrete cladding ranked third. CO2 emissions are considered the most critical criterion, with nearly 10 percentage points more over the second most valued criterion, cost.

DECISION GROUP - All Stakeholders								
AVERAGE WEIGHT	29%	13%	18%	14%	9%	16%		
ALTERNATIVES	CO2 emissions	Potential for recycling	Cost	Availability	Weight	Operational life	AVERAGE	
Timber Cladding	0,29	0,06	0,18	0,14	0,03	0,09	**0,79**	1
Concrete Cladding	0,08	0,07	0,13	0,07	0,03	0,16	**0,55**	3
Steel Cladding	0,10	0,13	0,17	0,05	0,09	0,12	**0,66**	2

Figure 18: MCDA analysis considering all stakeholder´s perspectives.

4.4. Exploring Scenario-based Decision-making: Influence of Changing Factors on MCDA Outcomes

This subchapter presents hypothetical scenarios, demonstrating how the cladding decision might vary with changes in the MCDA parameters. It is important to emphasize that both scenarios are based on hypothetical events, with the criteria weights and scores serving as illustrative examples. Thus, the results should be interpreted and analysed with caution, being simulations with no relation with the status of the case study. Two scenarios are presented.

Scenario 1 – Traditional time-cost-quality view, a weight re-evaluation

The motivation behind scenario one is to investigate how changes in the weight of the criteria impact the results of the MCDA. Based on the results obtained from the MCDA prototype developed in the previous subchapters, the aim is to understand what would happen to the recommended decision if the weights of the criteria for each stakeholder were evaluated differently. To this end, new weights were stipulated for the criteria, considering a vision with a more specific thematic focus for each stakeholder.

Scenario 2 – What if the Decision was affected by external events

The motivation behind scenario two is to investigate how changes in the criteria scores of the alternatives can influence and modify the recommended decision, affecting the results of the MCDA. Internal factors, such as changes in the project's budget, schedule or priorities, and external factors, such as new regulations, technological advances, fluctuations in material prices throughout the project's life cycle or changes in climatic conditions, can impact these scores. These unforeseen changes challenge companies in the construction sector to re-evaluate their decision. Simulating hypothetical events allows to assess the strength of the decision and the ability to adapt to unforeseen changes. This approach provides an analysis of how different situations can impact the decision, allowing the analysis to identify which criteria are most critical and which decisions are most robust in the face of change. By anticipating possible variations and their impacts, MCDA as a strategic tool can help decision-makers evaluate and prioritise various options based on multiple criteria scores, and better prepare to face uncertainties.

4.4.1. Scenario 1 – Traditional Time-Cost-Quality View, a Weight Revaluation

For scenario one, a hypothetical scenario was created in which the project adopts a more traditional approach, using the so-called "Iron Triangle". Here, stakeholders adopt a more traditional role view. This scenario will affect how the weight is distributed for each stakeholder, seen in figure 19.

STAKEHOLDER ANALYSIS

	CO2 Emission	Potential for Recycling	Cost	Availability	Weight	Operational Life
Buisness Manager	10%	5%	35%	15%	5%	30%
Env. Specialist	35%	30%	5%	5%	5%	5%
Env. Specialist	30%	35%	10%	5%	5%	15%
Project Manager	15%	10%	30%	25%	5%	15%
Client	10%	5%	30%	20%	5%	30%
Structural engineer	10%	10%	20%	15%	25%	20%
Architect	10%	10%	20%	15%	25%	20%

Figure 19: Re-distribution of weights for each stakeholder. Follows a more traditional view of the stakeholder’s role and perspectives.

Stakeholders naturally prioritize different criteria based on their roles. Thus, in this scenario a revaluation of the criteria weight is done in comparison to the results of figure 13. Hence, the business manager, Client and project manager are goal oriented towards cost being more important. The environmental specialists concern is regarding environmental sustainability and the structural engineers, and architect believes that the technical criteria are of most importance.

For comparison purposes, the different group arrangements presented in the subchapter “Power-Interest Matrix” continues here. However, the weights that each actor assigned to the criteria were changed to reflect a more traditional project approach. The three arrangements for this scenario are as follows:

- **DECISION GROUP – Client**: This group consists solely of the Client, who has high power and high interest in the decision-making process.
- **DECISION GROUP – Key Players**: This group includes the Key Players, being the Client, Project Manager, and Architect, all of whom have high power and high interest in the decision-making process.
- **DECISION GROUP – All stakeholders**: This group comprises all stakeholders, with varying levels of power and interest in the decision-making process.

DECISION GROUP – Client

A re-evaluation of the Client´s weight, where cost, operational life and availability have gained a larger preference still generated timber cladding as the preferred alternative (figure 20). There is a minimal difference between the average results of the three alternatives.

		DECISION GROUP - Client							
	WEIGHT	10%	5%	30%	20%	5%	30%		
		CO2 emissions	Potential for recycling	Cost	Availability	Weight	Operational life	AVERAGE	
ALTERNATIVES	Timber Cladding	0,10	0,02	0,30	0,20	0,02	0,18	**0,81**	1
	Concrete Cladding	0,03	0,03	0,22	0,10	0,01	0,30	**0,69**	3
	Steel Cladding	0,04	0,05	0,28	0,07	0,05	0,23	**0,70**	2

Figure 20: Re-evaluated MCDA analysis considering the Client´s new weight.

DECISION GROUP – Key Players

Based on the average criteria established by the Key Players group, the Timber external cladding is still the preferred decision (figure 21). The combination of priorities more focused on technical aspects by the Architect, together with the economic priorities of the Client and Project Manager, results in the environmental criteria being less valued. However, the fact that the timber alternative outperforms the other alternatives even in these criteria contributes significantly to the result. Despite having a lower performance in the other criteria of Recycling Potential, Weight, and Operational Life, it does not interfere with the selection of timber as the alternative for the project.

		DECISION GROUP - Key Players							
	AVERAGE WEIGHT	12%	8%	27%	20%	12%	21%		
		CO2 emissions	Potential for recycling	Cost	Availability	Weight	Operational life	AVERAGE	
ALTERNATIVES	Timber Cladding	0,12	0,04	0,27	0,20	0,04	0,13	**0,78**	1
	Concrete Cladding	0,03	0,04	0,20	0,10	0,03	0,22	**0,63**	3
	Steel Cladding	0,04	0,08	0,25	0,07	0,12	0,16	**0,72**	2

Figure 21: Re-evaluated MCDA analysis considering the Client´s, Project manager´s & Architect´s new weights.

DECISION GROUP – All stakeholders

Considering the collective average weights and preferences of all stakeholders in a hypothetical scenario with a more traditional design approach shows that the Steel cladding is considered the preferred alternative (figure 22). In this scenario, the weight of the criteria is distributed more evenly because it considers the priorities of all the different stakeholders equally, with more balanced environmental, economic, and technical aspects, presenting a range between the criteria of less than 10%. In this scenario, the criterion with the highest priority weight is Operational Life, with the Concrete cladding having the best performance. However, in the combination of the other criteria values, the Steel cladding shows a better average than the other alternatives, with the worst performance only in the Availability criterion, and standing out in the Potential for Recycling and Weight criteria.

		DECISION GROUP - All Stakeholders							
	AVERAGE WEIGHT	16%	14%	21%	14%	14%	21%		
		CO2 emissions	Potential for recycling	Cost	Availability	Weight	Operational life	AVERAGE	
ALTERNATIVES	Timber Cladding	0,16	0,06	0,21	0,14	0,04	0,13	**0,73**	2
	Concrete Cladding	0,04	0,07	0,15	0,07	0,04	0,22	**0,60**	3
	Steel Cladding	0,06	0,14	0,19	0,05	0,14	0,16	**0,74**	1

Figure 22: Re-evaluated MCDA analysis considering all stakeholders new weights.

4.4.2. Scenario 2 – What if the Decision was Affected by External Events

As an analytical exercise, this scenario proposes to explore how changes in the scores of the criteria associated with different external cladding alternatives impact the decision-making process. This is done by considering hypothetical events, where factors, both internal and external to the project, influences the variations in values. For this exercise, only the Client's weight distribution will be analysed since the Client was considered to the actor with the final input on the project's decisions. For this exercise three different hypothetical events serve as evaluation to see whether there would be any changes in the cladding decision. The three hypothetical events are:

- **EVENT 1:** Wood scarcity.
- **EVENT 2:** Incentives for the concrete industry to be more environmentally sustainable.
- **EVENT 3:** Large-scale implementation of the use of recycled steel.

Hypothetical Event 1 – Wood Scarcity

During the years 2020 to 2022, there was a shortage of wood on the European market, which directly affected the price of the raw material on the Swedish domestic market. As analysed in the Producer Price Index (PPI) table, 2020=100 by products, the change in cost between 2020 and 2022 was 48.5% (SCB - Statistikmyndigheten, 2024). Thus, considering a hypothetical future event, where there is a reduction in availability, the price of timber is likely to increase due to supply constraints. This could make timber material more expensive relative to other materials increasing the price by 48,5%.

A shortage also impacts the availability of the material, which could lead to project delays, increased project planning times, and forcing contractors to consider alternative materials or import the raw material from other continent; A shortage might also mean that lower quality or less durable species of wood might be used, potentially affecting the Operational life of the cladding system lower than standards.

ALTERNATIVES	Event 1 - Wood scarcity							
CLIENT WEIGHT	21 %	17 %	17 %	17 %	13 %	16 %		
	CO2 emissions	Potential for recycling	Cost	Availability	Weight	Operational life	AVERAGE	
Timber Cladding	0,21	0,07	0,12	0,08	0,04	0,06	**0,60**	3
Concrete Cladding	0,06	0,09	0,13	0,17	0,04	0,16	**0,64**	2
Steel Cladding	0,08	0,17	0,17	0,11	0,13	0,12	**0,77**	1

Figure 23: MCDA analysis considering a Hypothetical event of Wood Scarcity.

In a hypothetical event where there is a shortage of wood available on the market, for example due to wildfires or other sectors' increasing demands, the decision on the alternative for the external cladding, based on the established criteria, indicates that wood would be the least preferred alternative (figure 23). The results indicate that, despite no changes in the criterion with the most influence for the Client (CO2 emissions), a significant increase in the cost, availability, and operational life of the raw material makes wood the least preferred option. As this event does not have a direct impact on the other materials, the steel cladding option shows to be the best alternative as it has better performance indicators in most of the relevant criteria.

Hypothetical Event 2 – Incentives for the Concrete Industry to be More Environmentally Sustainable

In a hypothetical event where the concrete industry transitions into adopting new sustainable production methods and new manufacturing technologies, through alternative cement materials, supported by new policies and regulations, the environmental impact and emissions could be significantly reduced. At the moment of this study, concrete manufacturer already practicing sustainability indicate that CO2 emissions could be reduced by 40% (Svensk Betong, 2022). Incorporating alternative materials into the production of environmentally friendly concrete, which are relatively new and have lower demand, can be more expensive than traditional method, increasing the construction cost price by 5% (Abou Hhalil & Tokovic, 2022). The new manufacturing concrete products could have difficulties to be found in a very established industry, needing to import the product from outside of Sweden and Nordic region.

	Event 2 - Incentives for the concrete industry to be more environmentally sustainable							
CLIENT WEIGHT	21 %	17 %	17 %	17 %	13 %	16 %		
ALTERNATIVES	CO2 emissions	Potential for recycling	Cost	Availability	Weight	Operational life	AVERAGE	
Timber Cladding	0,21	0,07	0,17	0,17	0,04	0,09	**0,75**	1
Concrete Cladding	0,10	0,09	0,12	0,06	0,04	0,16	**0,56**	3
Steel Cladding	0,08	0,17	0,15	0,06	0,13	0,12	**0,70**	2

Figure 24: MCDA analysis considering a Hypothetical event of Incentives for the concrete industry to be more environmentally sustainable.

A hypothetical event to incentive the concrete industry to become more environmentally sustainable would not be enough to make the Concrete cladding alternative the most preferrable for the project based on the Client´s perspective (figure 24). Even with the concrete cladding becoming more environmentally friendly with the decrease of CO2 emissions, the average score on the other criteria still impacts the concrete alternative to its disadvantage and the fact that the availability of environmentally friendly concrete is becoming more difficult to access contributes to the result. Seeing that the Client prioritises the CO2 emissions, cost, and availability, in which the timber cladding has it advantage, the recommended decision still becomes the timber cladding.

Hypothetical Event 3 – Large-Scale Implementation of the Use of Recycled Steel

Using recycled steel significantly reduces CO2 emissions by 80% compared to producing new steel from iron ore (Holappa, 2020). The recycling process is less energy-intensive as it bypasses the energy-demanding steps of mining, transporting raw materials, and initial smelting (Hillebrandt et al., 2019).

Recycled steel costs 20-30% more due to various barriers; Financially, there are difficulties in obtaining low-cost capital and long payback periods discourage investment; Commercially, subsidies for conventional methods and a lack of environmental regulations reduce the competitiveness of recycled steel; In addition, production costs are high due to the use of new technologies, such as DRI plants based on renewable hydrogen, which do not yet benefit from economies of scale (International Renewable Energy Agency, 2023). As recycling processes become more widespread and efficient, recycled steel could become more readily available on the market, being less subject to the volatility of raw material. There is a need to specify that these are hypothetical events, and there are several factors that could provoke a change in the criteria values. However, based on sources in this scenario and the limits of the study, this hypothetical scenario is selected and limited to above stated changes.

Event 3 - Large-scale implementation of the use of recycled steel								
CLIENT WEIGHT	21 %	17 %	17 %	17 %	13 %	16 %		
ALTERNATIVES	CO2 emissions	Potential for recycling	Cost	Availability	Weight	Operational life	AVERAGE	
Timber Cladding	0,09	0,07	0,17	0,17	0,04	0,09	**0,63**	2
Concrete Cladding	0,03	0,09	0,12	0,08	0,04	0,16	**0,51**	3
Steel Cladding	0,21	0,17	0,12	0,17	0,13	0,12	**0,91**	1

Figure 25: MCDA analysis considering a Hypothetical event of Large-scale implementation of the use of recycled steel.

Considering a hypothetical event in which the large-scale implementation of the use of recycled steel is successfully achieved in the construction sector, the steel cladding would be the most preferred alternative according to the evaluation of the Client's criteria (figure 25). Despite being the more expensive option among the others, steel cladding would perform as well as or better than the other alternatives in almost all indicators, especially in terms of CO_2 emissions. In addition, the recycling potential, which showed no reduction in the values related to this criterion, would still outperform the other alternatives.

CHAPTER 5

DISCUSSION

SUMMARY

In this chapter, the results from the literature review, case study, interviews, questionnaire, and developed prototype are interpreted, analysed, and discussed based on the methodology approach within the context of the proposed research aim and objectives of this study.

The results obtained in this research support existing theories of the importance of integrating and engaging multiple criteria and stakeholder perspectives in complex project environments. The findings contribute to new insights into how MCDA can be applied in practice in construction projects to improve decision-making processes and consider a multi-actor scenario. The MCDA prototype results illustrate the same recommended decision of timber cladding as in the actual case project. Showcasing that multi-criteria decision analysis is a compatible tool for supporting the decision-making process. Although the MCDA tool resulted in the same decision as the project team made independently in the case project, this might not always be the case. Then the benefit of using MCDA lies in its structured, transparent, and objective approach to decision-making where MCDA is particularly valuable in more complex scenarios where the optimal decision is not as obvious. It helps to identify and weigh competing priorities and potential trade-offs effectively, ensuring that all relevant factors are considered and that decisions are well-informed and justifiable.

Our results show that when introducing several stakeholders into the decision-making process, the recommended decision still did not change. Why the decision did not change can be backed up by the highlights of the recurring themes in the interviews, where participants stressed the importance of having clear goals. The ambitious sustainability targets in the studied case study project where, for instance, the Client's goal of reducing carbon emissions by 50% was a driving factor. This clear ambition made it possible for the project team to always be aware of how the decisions were considered and evaluated, making the decision-making process more streamlined and focused. With clear and ambitious goals, the project team could prioritize decisions that aligned with these targets. This alignment minimized conflicts and facilitated consensus among stakeholders, as everyone understood the overarching objectives. The interviews further revealed that stakeholders felt a sense of shared responsibility and commitment to achieving these goals, which reinforced their collective decision-making.

The importance of effective stakeholder management becomes evident when considering the benefits observed in the results. Clear communication, well-defined goals, and a collaborative environment played crucial roles in aligning the stakeholders' interests. Regular meetings and transparent decision-making processes ensured that all parties were informed and engaged, reducing the likelihood of conflicts. However, in scenario one[1], which illustrated the absence of unified goals among stakeholders led to different recommendations based on the stakeholders included in the decision process. What is interesting with these results are that even with fragmented priorities, MCDA can solve these potential conflicts by balancing the stakeholders' views and resolve to one recommended decision.

Furthermore, the use of MCDA proved to be effective for evaluating possible events that influence the project throughout its life cycle. This method made it possible to compare different alternatives and how these impacts the decision-making process, presenting a potential approach for strategic planning in projects.

There is a fragile line on what is objectively true in this paper, and the results themself need to be analysed with caution as some of the data (Scenario 1 & 2) are based on hypothetical events. The inclusion of hypothetical scenarios to explore how different circumstances might impact the decision-making. While these scenarios provide insights into how project managers can think on potential future events, they are based on assumptions that may not capture the complexities of real-world situations. For example, the hypothetical event of wood scarcity assumed a specific percentage increase in cost and a decrease in availability, but real-world market dynamics can be more unpredictable and influenced by numerous factors not accounted for in the scenario. Nevertheless, it shows how the method could be used to simulate possible future events and, thus, highlighting possible risks early in the project. Our findings thereby indicate new areas that to our knowledge has not been extensively studied before.

These hypothetical scenarios, while illustrating an idea on how the uncertainties on the future might affect potential decision outcomes, the data itself is speculative and the results from these scenarios should be interpreted with caution.

Moreover, the recommended decision is only true for this particular decision activity, with this interviewed project team, in this construction project, and should not be extrapolated. If any of these parameters would be changed, the MCDA would be invalid. In that sense the recommended decision results themself cannot be generalised. What that means is that the MCDA results only work in the framework in which the decision is set. However, in this study, it is not the recommended decision itself that is interesting to analyse, but the idea of MCDA as a supportive tool for project teams to use. What the thesis has

[1] Scenario one: Traditional time-cost-quality view, a weight re-evaluation

illustrated is that MCDA tools have the capability to help project teams to objectively structure, identify, analyse, and decide on complex issues in construction projects. These tools facilitate a systematic approach to decision-making by breaking down the problem into manageable components and evaluating them based on quantifiable criteria.

MCDA tools also play an important role in enhancing transparency and improving feedback mechanisms within decision-making processes in construction projects. By offering a structured approach to evaluating multiple factors, these tools ensure that every stakeholder understands how decisions are made. The explicit definition and weighting of each criterion provide a clear and objective basis for decision-making, fostering trust among stakeholders who can see that choices are based on quantifiable data rather than subjective opinions. This transparency is crucial in complex projects where diverse interests must be balanced. Furthermore, MCDA tools facilitate robust feedback mechanisms by detailing how each decision was reached, allowing stakeholders to review, discuss, and provide targeted feedback. This iterative process leads to continual refinement and improvement of decisions for the future.

However, MCDA at the same time demands a lot of attention to be able to provide detailed results. This research applied two of many techniques in multi-criteria analysis. The Simple Additive Weighting (SAW) methodology is known for its simplicity and ease of use. Although SAW is straightforward, it assumes linearity in the decision-making process and may not capture the complexities of some decision contexts as effectively as other methods. Furthermore, the Analytical Hierarchy Process technique (AHP), which is a widely used method for structuring decision problems and multi criteria analysis. However, it has its complications as it often is time-consuming and cognitively demanding on the participants. This leads to inconsistencies on the pairwise results, which could lead to the results becoming unreliable. Also, other MCDA techniques might offer different insights and potentially different results in certain contexts. Thus, the inclusion or exclusion of one or other MCDA techniques might not capture the full range of possibilities in the results that other methods might provide.

Secondly, there exist a paradox within the relation between MCDA and construction projects. As mentioned before, MCDA demands time and information to be able to present recommendations. With that, the more precise the data is, the better recommendations can the MCDA present. However, in construction, decisions often must be made quickly and with incomplete information. This industry is characterized by its dynamic nature and the necessity to adapt to unexpected challenges, such as sudden changes in material availability. Consequently, project teams frequently rely on experience and intuition, rather than comprehensive data analysis. This urgency and the often-fragmented data landscape in construction can lead to decisions that might not be optimal or fully informed. Despite the potential of MCDA to offer more structured and rational decision-making, its practical application is sometimes hindered by the need for rapid responses and the lack of detailed information at critical decisions. Therefore, while MCDA can significantly enhance decision quality when time and information are available, the construction industry must find a balance between data-driven methods and the practical realities of its fast-paced environment. This highlights the need for improving data collection and integration processes within construction projects to better support the effective use of MCDA tools.

CHAPTER 6

CONCLUSION

SUMMARY

This chapter presents the conclusions related to the two research questions outlined in subsection 1.3 and discusses the corresponding limitations of this study while providing recommendations for continued work and future research.

This research underscores the potential of Multi-Criteria Decision Analysis (MCDA) tools in enhancing decision-making processes in construction projects. By integrating and engaging multiple criteria and stakeholder perspectives, MCDA facilitates structured, transparent, and rational decision-making, crucial in the complex and dynamic environment of construction. The findings demonstrate that MCDA supports project teams in structuring, identifying, analysing, and deciding on complex issues, leading to informed decisions that align with project goals despite uncertainties.

In the case project studied, MCDA led to a consistent recommended decision, even with multiple stakeholders involved. This consistency was largely attributed to the clear sustainability goals set by the project, ensuring all stakeholders were aligned and focused on common objectives. This alignment minimized conflicts and facilitated consensus, highlighting the importance of well-defined goals and effective stakeholder management.

MCDA's capability to evaluate stakeholder influence on the decision-making process was evident, as it integrates and balances multiple perspectives, ensuring that all relevant views are considered transparently and objectively. The structured framework of MCDA proved valuable in scenarios with fragmented priorities, resolving potential conflicts by balancing diverse stakeholder views, demonstrating its effectiveness in handling complex decision-making environments typical of construction projects.

Furthermore, MCDA enhances transparency and improves feedback mechanisms, but it is also demanding and can lead to inconsistencies if not carefully managed. The use of the Analytical Hierarchy Process (AHP) technique in this study, though effective, illustrated the cognitive and time burdens placed on participants, which can affect the reliability of the results. Therefore, there is a need to explore other MCDA techniques that might offer different insights or be better suited to specific contexts within construction projects.

The inclusion of hypothetical scenarios provided valuable insights into how different circumstances might impact decision-making, though these scenarios are based on assumptions that may not fully capture the complexities of real-world situations. Therefore, while useful for exploring potential future events and market changes, their results should be interpreted with caution.

In conclusion, this thesis illustrates that MCDA tools have the capability to significantly improve decision-making in construction projects by providing a structured, transparent, and objective framework. However, their practical application requires careful management of the time and information demands, and a balance with the industry's need for rapid decision-making. Future research should focus on improving data collection and integration processes in construction projects and can explore other MCDA techniques beyond AHP and study how different techniques differentiate in the recommended decisions. Comparing the effectiveness and suitability of these techniques in the context of construction projects can evaluate the differences and identify the more suitable approaches for construction projects and decision scenarios.

Moreover, to enhance the generalisability and robustness of utilizing MCDA applications, future research can examine construction projects across various geographical, cultural, and decision-making contexts. Furthermore, understanding how different regulatory requirements, and cultural factors influences the decision-making would also contribute to this field of research. Expanding the scope to include multiple decision activities within various projects can also develop a more holistic understanding of the effectiveness on utilizing MCDA. This approach could ensure that MCDA can effectively be used to manage different complexities in diverse construction project settings.

Furthermore, given the limitation of social inclusion in this study, future research can place a greater emphasis on incorporating social criteria into the MCDA framework, trying to understand the social impact on decision-making process of construction projects.

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APPENDICES

APPENDIX A – INTERVIEW QUESTIONS

Project Overview and Objectives:

1. What is your role and expertise in the project, and to what extent are you involved?
    - In which activities, if any do you influence the project decision process?
2. Can you describe how a typical decision is made in the project, who takes the decision and how is the decision made?
3. What activity are you currently carrying out in the project? What important decisions were you involved in that you consider to be essential for the project so far?

Decision Criteria:

4. What criteria do you consider important (greatest impact) when making decisions within the context of construction projects? (e.g., we often discuss the idea of sustainability, what do you see as important when discussing environmental, social, or economic aspects?)
5. How do you determine the significance of criteria in your decision process and are any of these criteria overlooked or considered less relevant? How do you balance or consider criteria outside of your expertise?
6. Could you describe your decision process and the key factors that influence your choices? Are there any information or data you see as essential to support your decisions in the project?

Decision-Making and Stakeholder Involvement:

7. What relations do you consider essential to support your decisions in the project? Which actors are involved in your network of activities and decisions?
8. In which situations has decision-making in construction projects been particularly challenging due to conflicts of interest between stakeholders, how was this managed?
9. How important is it, in your opinion, for all stakeholders to be involved in the project's decision-making process?

APPENDIX B – QUESTIONNAIRE

STAKEHOLDER QUESTIONNAIRE

Chalmers Master´s Thesis – Design and Cosntruction Project Managment

Decision Making Process in Construction Projects

Start

Instructions

Thank you again for your time dedicated to our thesis. Your participation is essential for our final outcome.

This questionnaire is important to better understand the decision-making process in construction projects. The aim is to effectively integrate multiple and often conflicting criteria, considering the diverse perspectives and values of stakeholders, in order to support a transparent decision-making process.

The questionnaire is divided into **three parts:**

Part 01 - **Multi-Actor Network:** Map and analyse the relationships between actors involved in the project.
Part 02 - **Criteria for Project:** Have a holistic view of how actors involved in the project weight criteria identified from the interviews.
Part 03 - **Cladding Decision Analysis**: Understand how the weight of criteria can impact a decision of a specific activity in the project, considering a range of alternatives.

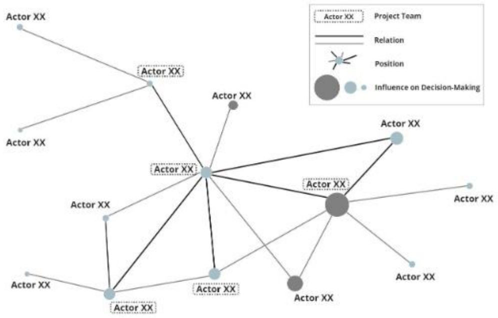
In Order to Continue Please Fill Your Name: (Names will not be published, they will serve as identification for us to organise the results)

Next

Part 01 - Multi-Actor Network

How are actors involved, how do they interact with each other in the project and by whom are decisions made?
We would like you to reflect on who you interact with during the project process and how you percieve each actor´s influence on the decision-making.

Our goal is to create a graph similar to the image below:



Next

Q.01 - Considering your role in the Project, how frequently were your collaborating with other actors involved in the project when you needed to take a decision?

Breif Explanation: This question aims to identify which stakeholders are involved in contributing to the decision specific to your role. It seeks to understand the dynamics and the various roles that different stakeholders play in the decision-making relevant to your position.

Rank

- **High Frequency:** Indicates that you were in constant communication and collaboration with the actor in question. You exchanged information, ideas and feedback regularly and met or communicated daily or several times a week.
- **Medium Frequency:** Indicates that you interacted periodically with the actor in question. You maintained consistent but not daily contact, which allowed for a continuous workflow and strategic alignment, but with room to work independently.
- **Low Frequency:** Indicates that you engaged occasionally, perhaps at monthly meetings or only at specific project milestones with the actor in question. Communication was generally focused on status updates or solving specific problems.
- **No Frequency:** This means that there was no regular or scheduled interaction with the actor in question. Communication occurred only in exceptional circumstances

*If your role is on the list you should mark as **High Frequency**

	No Frequency	Low Frequency	Medium Frequency	High Frequency
Client				
Tenant (Final User)				
Architect				
Project Manager				
Business Manager				
Environmental Specialist				
Structural engineer				
Consultant (Acoustic)				
Consultant (HVAC)				
Consultant (Fire/Safety)				
Supplier				
Subcontractor				
Government (Regulatory Agencies)				
Legal Advisors				

Next

Q.02 - Please rank these actors in sequence of who you believe has the most influence (in general) on decisions in the Project

Breif Explanation: We want to evaluate the impact actors have on the decision-making process in the project. Respondents are expected to rank the actors in a sequence that starts with the one they consider to have the greatest influence on decisions down to the one with the least influence.

*You need to drag the options into the box on the right and rank the actors in order of influence

Drag your choices here to rank them

- Client
- Tenant (Final User)
- Architect
- Project Manager
- Business Manager
- Sustainability Specialist
- Structural engineer
- Technical Consultant
- Supplier
- Regulatory Agency (Municipality)

Next

Part 02 - Criteria for the Project

In part 02 we want to see how actors weight criteria after what they see as important, and how this difference of values can reveal potential conflicts or areas of consensus.

A Pairwise Comparison system will be used to evaluate the different criteria that were identified during interviews. Use the following scale to rank your answers:

1: Equal Importance - Both options contribute equally to the criterion.
3: Moderate Importance - Experience and judgement slightly favour one cirteria over the other.
5: Strong Importance - Experience and judgement strongly favour one cirteria over the other.
7: Very Strong Importance - A criteria is favoured very strongly over the other.
9: Extreme Importance - The evidence favouring one criteria over the other is of the highest possible order of affirmation.

Next

Q.03 - SUSTAINABILITY CRITERIA

Environmental: Environmental criteria ensure the sustainability of the building materials and practices.

Economic: Economic criteria help in evaluating the financial viability and cost-effectiveness.

Social: Social criteria assess how the building contributes to the quality of life and societal progress.

Technical: Technical criteria deals with the functional and practical aspects of the design and construction.

Rank Scale

1: Equal importance; 3: Moderate importance of one over another; 5: Strong importance of one over another; 7: Very strong importance of one over another; 9: Extreme importance of one over another.

	9	7	5	3	1	3	5	7	9	
Environmental										Economic
Environmental										Social
Environmental										Technical
Economic										Social
Economic										Technical
Social										Technical

Next

Q.04 - ENVIRONMENTAL SUB-CRITERIA

GWP (Global Warming Potential): Building materials impact on climate change by quantifying the total carbon dioxide (CO_2) emitted over its lifecycle.

Potential to Reuse: The ability of building materials to be repurposed or recycled, reducing waste in construction projects.

Biodiversity: The ecological footprint of resource utilization in building operations and material selection, mitigating adverse impacts on biodiversity.

Energy Efficiency: Aiming to minimize energy consumption through smart design, advanced materials, and efficient systems.

Rank Scale

1: Equal importance; 3: Moderate importance of one over another; 5: Strong importance of one over another; 7: Very strong importance of one over another; 9: Extreme importance of one over another.

	9	7	5	3	1	3	5	7	9	
GWP (Global Warming Potential)										Potential to Reuse
GWP (Global Warming Potential)										Biodiversity
GWP (Global Warming Potential)										Energy Efficiency
Potential to Reuse										Biodiversity
Potential to Reuse										Energy Efficiency
Biodiversity										Energy Efficiency

Next

Q.05 - ECONOMIC SUB-CRITERIA

Initial Cost: Upfront expense for materials and design of the building.

Construction Cost: Expenses incurred during the building phase of the building.

Operational Cost: Cost of maintaining and operating the building over time.

End of Life Cost: Costs associated with dismantling and disposing of the building.

Rank Scale

1: Equal importance; 3: Moderate importance of one over another; 5: Strong importance of one over another; 7: Very strong importance of one over another; 9: Extreme importance of one over another.

	9	7	5	3	1	3	5	7	9	
Initial Cost										Construction Cost
Initial Cost										Operational Cost
Initial Cost										End of Life Cost
Construction Cost										Operational Cost
Construction Cost										End of Life Cost
Operational Cost										End of Life Cost

Next

Q.06 - SOCIAL SUB-CRITERIA

Aestetics: Visual and sensory appeal of a building, including its design, materials, and integration with the surrounding environment to enhance cultural and contextual relevance.

Quality of spaces: End users are provided with spaces designed to enhance well-being and social interaction. Key factors include thermal comfort; air quality; acoustic comfort; and visual comfort.

Safety & Security: Minimize dangers within and around buildings, enhancing occupant comfort by reducing risks of assault and incidents through strategic measures like improved visibility, lighting, clear path layouts.

Innovation: The incorporation of innovative and pioneering design, technologies, and practices in the building process. Aiming to improve efficiency, sustainability, and user experience.

Rank Scale

1: Equal importance; 3: Moderate importance of one over another; 5: Strong importance of one over another; 7: Very strong importance of one over another; 9: Extreme importance of one over another.

	9	7	5	3	1	3	5	7	9	
Aestetics										Quality of spaces
Aestetics										Innovation
Aestetics										Safety & Security
Quality of spaces										Innovation
Quality of spaces										Safety & Security
Innovation										Safety & Security

Next

Q.07 - TECHNICAL SUB-CRITERIA

Quality / Maintainability: Materials and methods used to ensure high standards of quality, ease of maintenance, and longevity, aiming to reduce the need for frequent repairs and replacements.

Constructability: Focusing on optimizing construction workflows, minimizing timeschedules, and simplifying implementation processes to achieve timely project completion.

Flexibility & Disassemble: The adaptability of building structures, allowing for easy modification and disassembly, which supports reconfiguration, reuse, and recycling of materials.

Certifications: The building meets established industry standards and achieves recognized certifications, reflecting compliance with environmental, safety, and quality benchmarks.

Rank Scale

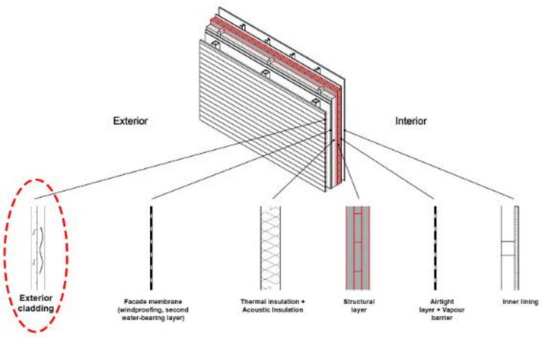
1: Equal importance; 3: Moderate importance of one over another; 5: Strong importance of one over another; 7: Very strong importance of one over another; 9: Extreme importance of one over another.

	9	7	5	3	1	3	5	7	9	
Quality / Maintainability										Constructability
Quality / Maintainability										Flexibility & Disassemble
Quality / Maintainability										Certifications
Constructability										Flexibility & Disassemble
Constructability										Certifications
Flexibility & Disassemble										Certifications

Next

Part 03 - Decision Analysis of Cladding Alternatives

We want to use cladding as an example to analyze the decision-making process. This will be a hypothetical exercise where you will answer questions about which cladding option, in your opinion, is the best fit for the Project.



Cladding refers to component that are attached to the primary structure of a building to form non-structural, external surfaces.

The alternatives to be evaluated are related to the main composition of the cladding finishing material. Following list are the materials considered: **Timber, Metal, Concrete**

Next

Q.08 - When deciding the cladding in the project, please indicate how much you participated in discussing the alternatives by selecting the statement that best describes your involvement:

- ◯ I was not involved in the decision-making process for the cladding.
- ◯ I provided input or feedback, but did not take any decisions.
- ◯ I actively discussed and helped somewhat on deciding the cladding alternatives.
- ◯ I was one of the main decision-makers for selecting the cladding.

Next

Q.09 - Assess the relavance of each criteria for the cladding system of the Project, focusing on their significance from the perspective of your role in the project.

Brief Explanation: This question aims to understand how you perceive the importance of various criteria in the choice of a cladding system in relation to your priorities. Your assessment will help us identify which criteria are most valued by different team members, ensuring that the final decisions reflect a wide range of needs and perspectives.

Scale system

A Scale 0-100, will be used to evaluate the criteria, where:

- 0 represents that the criteria is NOT important at all when selecting a cladding system.
- 100 means that the criteria is really important when deciding a cladding system.
- Intermediate values between 0 and 100 should be used to represent gradations of importance, with higher numbers indicating a greater level of importance.

NOTE! You are NOT required to make all the criteria add up to 100. Each criteria is separate, and you should give each a 0-100 score based on its own relevance. Thus, several criteria could have the value 100!

	0 – 100
CO2 Emission: Measures the amount of carbon dioxide released as a result of manufacturing, transporting, and installing the cladding material.	
Potential for Recycling: Evaluates the capability of the material to be recycled or repurposed at the end of its life.	
Aesthetic: Considers the visual appeal and architectural integration of the cladding material.	
Low or Non-toxic: Assesses the health and environmental risks associated with the material during its lifecycle, including production, installation, and disposal.	
Construction Unit Price: Refers to the cost per unit (e.g., per squaremeter or per panel) of the cladding material.	
Maintenance Cost: Estimates the ongoing costs to maintain the cladding material over time, including repairs, and replacements.	
Availability: Assesses the ease of sourcing the cladding material.	
Weight: Considers the mass of the cladding material per unit area. Heavier materials may require more robust structural support.	
Fire Resistance: Evaluates the material's ability to resist fire, prevents the spread of flames and maintains structural integrity under high temperatures.	
Operational Life: Looks at the durability and the longevity of the material. Includes how often maintenance is required and how vulnerable the material is to damage.	

Next

That is All.
Thank you for your collaboration!!

If you have any Comments/Suggestions you would like to add, please fill in below:

Done

APPENDIX C – PRIORITISED SUB-CRITERIA DESCRIPTION

CRITERIA		DESCRIPTION
1.	ENVIRONMENTAL	Environmental criteria ensure the sustainability of the building materials and practices.
1.1.	GWP (Global Warming Potential)	Building materials impact on climate change by quantifying the total carbon dioxide (CO_2) emitted over its lifecycle.
1.2.	Potential to Reuse	The ability of building materials to be repurposed or recycled, reducing waste in construction projects.
1.3.	Biodiversity	The ecological footprint of resource utilization in building operations and material selection, mitigating adverse impacts on biodiversity.
1.4.	Energy Efficiency	Aiming to minimize energy consumption through smart design, advanced materials, and efficient systems.
2.	ECONOMIC	Economic criteria help in evaluating the financial viability and cost-effectiveness.
2.1.	Initial Cost	Upfront expense for materials and design of the building.
2.2.	Construction Cost	Expenses incurred during the building phase of the building.
2.3.	Operational Cost	Cost of maintaining and operating the building over time.
2.4.	End of Life Cost	Costs associated with dismantling and disposing of the building.
3.	SOCIAL	Social criteria assess how the building contributes to the quality of life and societal progress.
3.1.	Aesthetics	Visual and sensory appeal of a building, including its design, materials, and integration with the surrounding environment to enhance cultural and contextual relevance.
3.2.	Quality of Spaces	End users are provided with spaces designed to enhance well-being and social interaction. Key factors include thermal comfort; air quality; acoustic comfort; and visual comfort.
3.3.	Safety & Security	Minimize dangers within and around buildings, enhancing occupant comfort by reducing risks of assault and incidents through strategic measures like improved visibility, lighting, clear path layouts.
3.4.	Innovation	The incorporation of innovative and pioneering design, technologies, and practices in the building process. Aiming to improve efficiency, sustainability, and user experience.
4.	TECHNICAL	Technical criteria deal with the functional and practical aspects of the design and construction.
4.1.	Quality / Maintainability	Materials and methods used to ensure high standards of quality, ease of maintenance, and longevity, aiming to reduce the need for frequent repairs and replacements.
4.2.	Constructability	Focusing on optimizing construction workflows, minimizing timeschedules, and simplifying implementation processes to achieve timely project completion.
4.3.	Flexibility & disassemble	The adaptability of building structures, allowing for easy modification and disassembly, which supports reconfiguration, reuse, and recycling of materials.
4.4.	Certifications	The building meets established industry standards and achieves recognized certifications, reflecting compliance with environmental, safety, and quality benchmarks.

APPENDIX D – CLADDING SUB-CRITERIA DESCRIPTION

CRITERIA		DESCRIPTION
1.	CO2 Emission	Measures the amount of carbon dioxide released as a result of manufacturing, transporting, and installing the cladding material.
2.	Potential for Recycling	Evaluates the capability of the material to be recycled or repurposed at the end of its life.
3.	Aesthetic	Considers the visual appeal and architectural integration of the cladding material.
4.	Low or Non-toxic	Assesses the health and environmental risks associated with the material during its lifecycle, including production, installation, and disposal.
5.	Construction Unit Price	Refers to the cost per unit (e.g., per square meter or per panel) of the cladding material.
6.	Maintenance Cost	Estimates the ongoing costs to maintain the cladding material over time, including repairs, and replacements.
7.	Availability	Assesses the ease of sourcing the cladding material.
8.	Weight	Considers the mass of the cladding material per unit area. Heavier materials may require more robust structural support
9.	Fire Resistance	Evaluates the material's ability to resist fire, prevents the spread of flames and maintains structural integrity under high temperatures.
10.	Operational Life	Looks at the durability and the longevity of the material. Includes how often maintenance is required and how vulnerable the material is to damage.

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