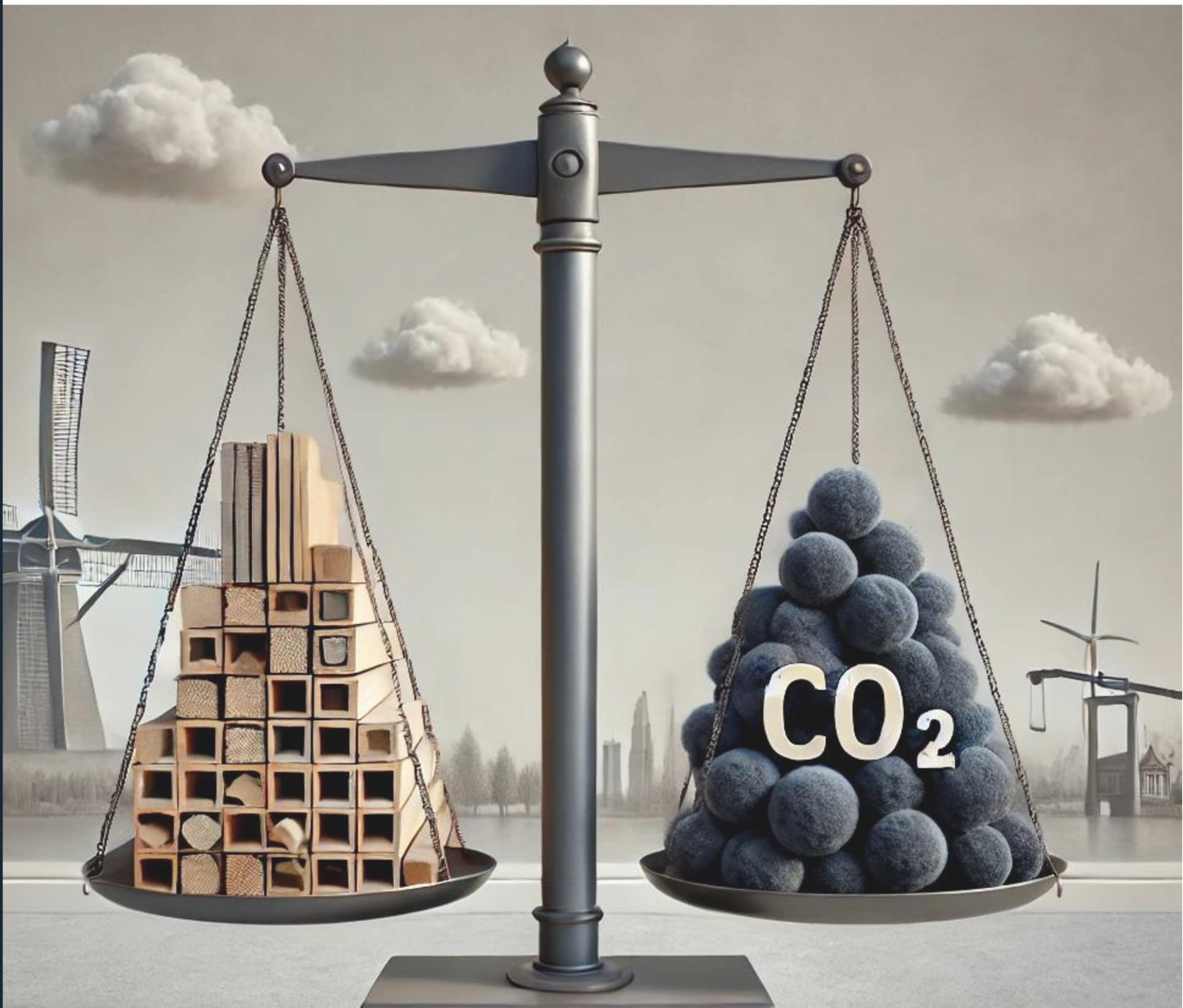
Enhancing the Decision-Making Process for Material Selection in the Netherlands

Strategies for Carbon Emission Reduction

Nikhil Varghese



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Enhancing the Decision-Making Process for Material Selection in the Netherlands: Strategies for Carbon Emission Reduction

by

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In partial fulfilment of the requirements for the degree of
Master of Science in Construction Management and Engineering *at the*
Delft University of Technology

In collaboration with ***Royal HaskoningDHV***

This thesis is confidential and cannot be made public until 20th August 2024

An electronic version of this thesis is available at
http://repository.tudelft.nl/.

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Acknowledgement

This thesis marks the end of my two-year journey as a Master's student at TU Delft. Since my arrival in Delft, it has been a rollercoaster of experiences. Over these years, TU Delft has shaped me both as a person and as an engineer. The hiccups and struggles I faced along the way have made me a much stronger individual. I am deeply grateful for the people I have met and the experiences I have gained throughout this journey.

Firstly, I would like to thank my thesis committee members. Foremost, my first supervisor, Arjen, who was always available to provide invaluable input and show his support, ensuring I was able to perform to the best of my abilities. I am immensely grateful for his guidance throughout this research. I also want to extend my sincere appreciation to my chair, Ad Straud, who was always ready for a meeting and, despite his busy schedule, made time for me, offering innovative ideas and sharing literature. His insights and encouragement have been instrumental in shaping my research. A special thanks goes to Sander for his invaluable feedback and suggestions, which have significantly molded my research. His constructive input has greatly improved the quality of my work. Additionally, I would like to express my heartfelt thanks to all the faculty members who were involved in my courses throughout my Master's program. Thank you all for the time and energy you invested in helping me improve my thesis and for your unwavering support and encouragement.

Secondly, I would like to thank my mentors and everyone from RHDHV. I was fortunate to be under Anton, who has been an unwavering support since the day I joined RHDHV. He was always ready to help and share his knowledge, and it was always a pleasure to hear him talk about his work and see the passion he has for his profession. I am also grateful to Khushboo, who constantly provided help and navigated me through everything from interviews to my research itself. I am grateful to have you in my corner, always helping me and suggesting ideas, and being a support throughout this thesis. They were my guides and provided valuable insights for which I am extremely grateful. I thank you both for spending your time and sharing your valuable experience with me. I would also like to thank everyone from RHDHV whom I have met throughout my thesis, from the interviews to those who provided valuable insights for my research. These past six months at RHDHV have been a journey of learning, and I am grateful to all.

Thirdly, I am fortunate to have a group of people whom I am grateful to call friends. To all of my CME batchmates who have been there for me, especially Shaun, Sandra, Rinu, Reshma, Maitri, and Melissa, you all have been there from the beginning, through hours of lectures and workshops, always being supportive. You all made this journey a fun ride. I cannot forget to mention the friends who have been with me through thick and thin, especially Ditto, Apsara, Ashiya, Rithu, Riya, Jagu, Swetha, and John. You all made sure to be always there for me. Additionally, the TKM gang deserves special mention, as they, even though were thousands of kilometers away, made me realize that distance only brings you closer.

Finally, to those who supported and believed in me the most—my family. Foremost, my Appa and Amma, who always had enduring confidence in me, prayed for me, and made sure I never lacked anything in life, being there whenever it mattered. To my loving sisters, Nimisha and Chippy Chechi, and to my Aliyans, Roshan and Ananthu, who were all more worried about my thesis than I was, I can't forget to mention my sweet nephew and niece, Nathu and Serama, whose smiles and laughter always lifted my spirits. I am incredibly lucky to have all of you who cared for and supported me throughout this journey.

I am deeply grateful for all the new people I've met and the relationships I've built during this time and even though my Master's journey ends here, I will strive to continue learning throughout my career.

Thank you for taking the time to read my thesis. I hope you find it both pleasant and informative.

Nikhil Varghese

Executive Summary

The Netherlands is facing increasing concerns regarding climate change and rising carbon emissions, with the building sector contributing a substantial amount of these emissions. Despite the Dutch government implementing numerous policies and regulations to tackle this issue, the industry still lags behind. A significant portion of these emissions is from embodied carbon, which arises from the procurement, transportation, and manufacturing of materials, accounting for up to half of a building's total emissions over its lifetime. Addressing embodied carbon is crucial for achieving emission reduction targets. The material selection process is particularly significant, as decisions on materials can greatly impact the carbon emissions produced. Proper material selection decisions can lead to better environmental outcomes. The design process plays a vital role in this context, as crucial material decisions are made during this phase. Each phase of the design process represents critical points where important decisions are influenced. The research specifically focuses on decision-making for architectural and structural elements, as these components are integral to the overall sustainability of building projects. This thesis therefore explores the complicated decision-making scenario by enhancing the design process itself, where the objectives are to identify key barriers to emission friendly material selection and to provide recommendations to overcome these barriers and enhance decision-making.

The research is conducted in collaboration with Royal HaskoningDHV, a leading consultancy and engineering firm with significant contributions in numerous sectors. Leveraging this partnership, the thesis aims to gain insights through the firm's extensive experience in the field to address the main research question:

How can the decision-making process for material selection for building components in the Netherlands be enhanced during the design phases to reduce carbon emissions?

The research employed a qualitative approach comprising a narrative literature review to identify and establish the theoretical context in the field of material selection. This initial review provided a foundation for understanding existing knowledge and gaps. To gain practical insights, the study first conducted initial exploratory interviews to gather broad perspectives and identify key themes. Interviews were the primary mode of research, offering different perspectives into the material selection decision-making process. Following the exploratory phase, detailed semi-structured interviews were conducted to understand how the current process works in practice and to identify the barriers faced. The data collected from these interviews were analyzed using thematic analysis with the reference management software Mendeley, where common themes were tagged and analyzed to uncover significant barriers and facilitators in the material selection process. Additionally, the research findings were validated through feedback from experts with over thirty years of experience, ensuring the recommendations are robust and applicable in real-world contexts.

The study explored the current building process and the decision-making environment, identifying critical points where material selection decisions occur within the design phase timeline. The main focus was on identifying potential barriers that hinder the decision-making process. The results revealed several key findings. The lack of initiative and the inability to make decisions early in the project phases reduce the opportunity to make critical decisions. Missing this opportunity often leads to difficult and expensive changes later in the project. Poor initial planning can result in the replacement of sustainable materials with cheaper, less sustainable options. Critical decisions heavily rely on reliable and accurate data, as well as knowledge about the emission impacts of materials. The absence of this information can lead to choosing familiar or less optimal materials over better alternatives. Certain decisions, such as cost estimation and other project context factors, require data from the project itself, which is often not available in the initial stages. This gap affects the ability to make informed decisions early on. The research also identified a disconnect between multiple stakeholders involved in the decision-making process. The findings pointed to a lack of transparency among them, and the topics of material selection and emission reduction were less frequently discussed. The timing of contractor involvement significantly impacts the decision-making process. Contractors focusing on profit can influence decisions based on their involvement timing. Early involvement gives them more control over decisions, while later involvement results in missing out on the practical input they provide.

To achieve better project outcomes and avoid drastic changes later in the project, it is crucial to overcome delays in decision-making at the early stages. The initial starting point should be to set goals and requirements during the feasibility phase of a project. This phase offers the highest impact and opportunity to make significant decisions. Setting objectives, strategies to achieve these objectives, and a cost estimate to identify the budget required to realize these strategies should be developed with the help of a sustainability consultant. This ensures the client's ambitions are directed into a realistic path, paving the way for a more concrete project direction. However, it is recommended to maintain a margin of error of 30% at such an early stage. To reduce this margin and mitigate the issue of lack of knowledge, the research identified a critical point within the design phase where the project could meet three criteria: sufficient influence to implement changes that reduce emissions, lower costs and lesser impact for design changes, and enough data to make informed decisions. This point, termed the "sweet spot," was found to be at the preliminary design phase. Making critical decisions and setting requirements at this phase would help establish a concrete direction for the project. This phase is also ideal for involving the tendering process and ensuring that emission constraints and budget constraints are clearly mentioned in the tender documents. Effective collaboration among stakeholders is essential for project success. The research recommends having multiple interdisciplinary meetings where the topic of material selection is included in the agenda, and sustainability consultants are involved. Additionally, frequent budget checks throughout the project should be implemented to ensure the project does not exceed the set budget. Regular price checks on individual elements during and between phases will help estimate potential cost changes.

To implement the recommendations effectively, it is suggested to start with a preliminary pilot project. This begins by setting and designing Key Performance Indicators (KPIs) to assess how each recommendation performs in a controlled environment. The KPIs should be based on the recommendations and objectives of the project. To take control of the project early, the inclusion of sustainability consultants is essential. Ensuring that the client is actively engaged in the decision-making process from the beginning allows for the setting of realistic objectives and strategies for the project. As the project reaches the preliminary design phase, concrete requirements should be established regarding the goals in terms of emissions and budget constraints, and these should be included in the tender documents. Organizationally, the implementation should start with acknowledging that issues exist in terms of transparency and engagement, which are vital to every project. Ensuring a collaborative and transparent working environment is crucial. All stakeholders or disciplines involved in a project should be well-informed of all discussions and activities. Continuous learning and training programs should be instituted to educate about tools and emission-friendly materials. From a financial perspective, the firm should implement a system of budget checks where each check is predetermined and planned from the beginning. Additionally, regular price checks on individual elements that could result in higher costs will help the project stay on course.

The research faced certain limitations, particularly the lack of interviews with key stakeholders such as clients and contractors. This gap resulted in a narrower understanding of the material selection process and missed the opportunity to gain broader insights from these perspectives. While the research was validated by experts with over three decades of experience, a practical application of the proposed recommendations through a pilot project would have provided more in-depth insights in a real-world context.

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List of Abbreviations

DNR-STB	- Standaardtaakbeschrijving
MPG	- MilieuPrestatie Gebouwen
RIBA	- Royal Institute of British Architects
ECI	- Early Contractor Involvement
TPD	- Traditional Project Delivery
KPI	- Key Performance Indicators
LEED	- Leadership in Energy and Environmental Design
BREEAM	- Building Research Establishment Environmental Assessment Method
HVAC	- Heating, Ventilation, and Air Conditioning
LCA	- Life Cycle Assessment
SO	- Schematic Design
VO	- Voorontwerp (Preliminary Design)
DO	- Definitief Ontwerp (Definitive Design)
TO	- Technisch Ontwerp (Technical Design)
MEP	- Mechanical, Electrical, and Plumbing
ANN	- Artificial Neural Networks
DBB	- Design-Bid-Build
REACH	- Registration, Evaluation, Authorisation, and Restriction of Chemicals
SCM	- Sustainable Construction Management
MCDA	- Multi-Criteria Decision Analysis

Chapter 1

Introduction

In the face of climate change, marked by rising temperatures threatening environmental and infrastructural stability, the Netherlands confronts an unprecedented challenge (IEA, 2022). This challenge is further intensified by population growth, exerting additional pressure on the already strained energy grid (Pascoe, 2023). Rising concerns about the availability and affordability of raw materials, coupled with the impacts of climate change, loss of biodiversity, and pollution to soil, air, and water, highlight the urgent need for a significant reduction in raw material usage and a radical improvement in their efficiency. This calls for a transition to an emission free economy (Planbureau voor de Leefomgeving, 2023).

In this context, the building sector emerges as a critical focal point, being a major consumer of energy and a significant contributor to carbon emissions globally—accounting for nearly 40% of energy usage and approximately 36% of carbon emissions (European Commission, 2020), the sector's role is pivotal. Recognizing this, the Netherlands has set up a few bold legislative actions, aiming for a substantial reduction in greenhouse gas emissions, a 50 percent reduction in the use of primary raw materials by 2030 (Planbureau voor de Leefomgeving, 2023), and a transition to climate neutrality by 2050 (Ministerie van Economische Zaken, 2020).

Despite the proven effectiveness of such policies in reducing carbon emissions, the construction industry in the Netherlands is lagging, the substantial carbon footprint of buildings originates not just from operational energy consumption but also from the embodied carbon inherent in the procurement, transportation, and manufacturing of construction materials (Tingley & Davison, 2011). The built environment's embodied carbon is a substantial contributor to global carbon emissions, accounting for approximately 11% of overall emissions in the construction industry (World Green Building Council, 2022). Thereby producing and contributing large amounts of carbon emission during a building's life, as depicted in figure 1.1. This substantial impact highlights the urgent need to reduce embodied carbon in building projects.

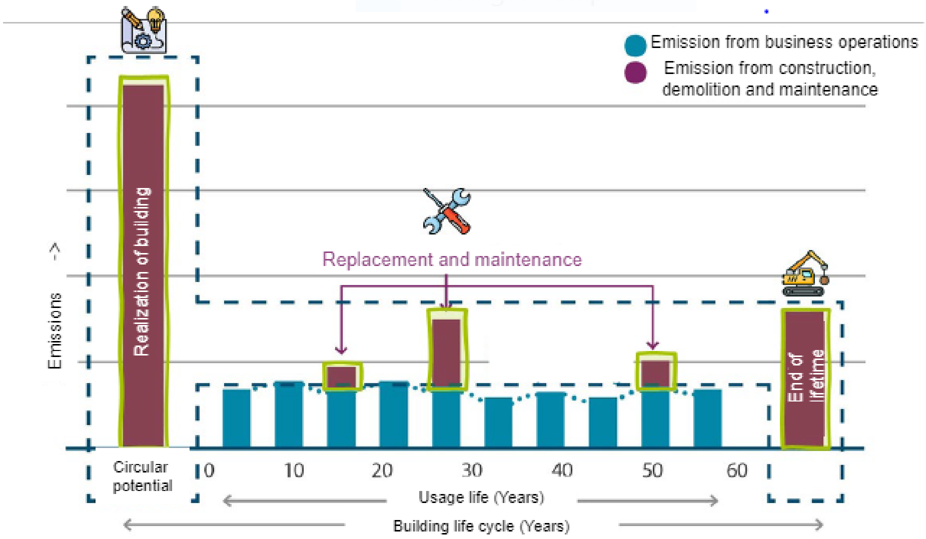

Figure 1.1: Whole life carbon per building phases (Royal HaskoningDHV, 2024)

1.1 Problem Definition

Material selection focused on the reduction of embodied carbon has been a prominent topic among researchers, given the complexity and vast options available in the construction industry (Lee, Lee, Lee, Kim & Kim, 2020). According to Wastiels, Wouters and Lindekens (2007), present material selection approaches prioritize material features above larger sustainability issues, resulting in ineffective decision-making, and with buildings significantly contributing to carbon emissions and resource consumption, there's a pressing need for a selection process that emphasizes decarbonization and emission reduction (Castro-Lacouture, Sefair, Flórez & Medaglia, 2009).

This gap underscores a critical need for a more structured and comprehensive approach to material selection. Proper decision-making in material selection is essential to achieve better and more successful results in construction projects (Qin, Li & Yang, 2023). The current design process often overlooks the potential of emission-friendly materials due to a lack of emphasis on them during critical design decisions (Tegegne, Abera & Alemayehu, 2023). The design phases are crucial for ensuring that material selection is well-considered, integrated, and aligned with the overall project goals. Each stage of the design phase serves as a critical point where material decisions are made. Enhancing these phases can lead to more informed and emission-friendly material choices.

This research aims to address the complex decision-making landscape by focusing on enhancing the design process itself. By examining the steps, phases, and methodologies of material selection from the outset, the goal is to integrate and promote an emission-free environment. This shift towards prioritizing emission reduction in the design process aims to bridge the gap between the current use of such materials and the Netherlands' ambitious environmental targets.

1.2 Research context

Royal HaskoningDHV is a leading global, project management, and consultancy firm with significant contributions across various sectors like public, social, industrial, and corporate real estate. They are recognized for their commitment to delivering innovative and sustainable solutions globally. In the Netherlands, their work is integral to developing the landscape and infrastructure, and they are committed to creating an emission-free environment that aligns with wider sustainability goals.

In this research, partnering with Royal HaskoningDHV aims to provide grounded insights specific to the Dutch context, leveraging the firm's extensive experience in sustainable practices. Through interviews with their staff, this research anticipates gaining a deeper understanding of effective material selection processes and sustainability practices that drive emission-free building projects. This collaboration is expected to offer mutual benefits, enhancing the research with real-world applications and supporting Royal HaskoningDHV in furthering their sustainability initiatives and material selection strategies.

1.2.1 Research Objective

The primary aim of this research is to develop a set of recommendations and suggest modifications that enhance the decision-making process during the design phases of building projects in the Netherlands, regarding material selection. This objective centers on embedding emission reduction criteria into the material selection process for architectural and structural elements. Research has shown that structural elements in buildings, such as steel and concrete, are responsible for the highest levels of embodied carbon (Fang, Brown, De Wolf & Mueller, 2023). Similarly, various studies on building materials have demonstrated the high amount of embodied carbon in structural elements (Hart, D'Amico & Pomponi, 2021). In addition, structural elements typically account for approximately 50-60% of the total direct construction cost (Romo-Orozco, Contreras-Jiménez, Corona-Armenta & Morales-Mendoza, 2022).

Another critical component in buildings that significantly impacts emissions is the architectural elements. Here, architectural elements mainly refer to the facade and exterior design elements. The facade can be considered the outer skin or surface of a building that consists of doors, windows, and decorative features (Krier & Vorreiter, 1988). Exterior design includes elements such as balconies, terraces, roofing, and visible structural elements that primarily contribute to the building's aesthetics rather than its structural integrity (Krier & Vorreiter, 1988).

Facade elements serve multiple purposes: protecting the building against environmental factors, and considering aesthetics and acoustics, which can result in conflicting outcomes (Mohammadi, Ramezanianpour & Erfani, 2022). The facade system can account for up to 25-40% of a building's total cost (Garmston, Pan & de Wilde, 2012) and covers 30-40% of a building's gross wall area (Guiles, 2020). As highlighted in the study by Ferreira, Pinheiro, De Brito and Mateus (2022), shell elements such as facades have substantial environmental impacts, with several facade materials having high embodied carbon. The study suggests that replacing traditional facade elements with more environmentally friendly options can significantly reduce embodied carbon. Therefore this research focuses on structural and architectural elements, aiming to provide solutions that integrate emission reduction into the material selection process.

The research mainly aims to address the following objectives

1. Analyze Decision-making Processes: Examine the existing decision-making processes for material selection and how and when decisions are being made.
2. Identify Barriers: Investigate and understand the challenges, and barriers that affect the decision-making process.

3. Enhance design process: Create a set of recommendations or strategies that prioritizes material emission reduction by enhancing the decision making process.

1.2.2 Research Questions

Main research question:

How can the decision-making process for material selection for building components in the Netherlands be enhanced during the design phases to reduce carbon emissions?

Sub-research questions:

- SQ1- What is the currently followed building process in the Netherlands and how are the design phases structured within this process?
- SQ2- Who are the stakeholders involved in the decision-making processes for material selection?
- SQ3-How are current decisions in material selection for architectural and structural elements structured during the design phase and at what stages of the project do these processes typically occur?
- SQ4- What are the key barriers influencing the decision-making process in material selection regarding emission reduction?
- SQ5- Based on identified barriers, what recommendations or strategies can be made to enhance the material selection process?

Chapter 2

Research methodology

The research methodology comprises a qualitative approach, in order to comprehensively address the topic and explore the various sub-questions. To effectively cover the subject matter, numerous research methodologies were considered. The selected methodologies are exploratory in nature. Primary data will be collected through literature reviews and semi-structured interviews.

Literature reviews were selected as a foundational method for this study to establish the theoretical context and to identify existing knowledge and gaps in the field. Semi-structured interviews were chosen to allow for in-depth discussions with industry professionals, capturing insights into their experiences and perspectives on material selection and emission reduction practices in construction.

2.1 Research Design

Developing a clear framework is essential while formulating preliminary ideas within the thesis themes. The design acts as a blueprint, encompassing the methodologies and approaches chosen for the research. The research design is divided into three distinct phases.

2.1.1 Phase 1 - Initial Investigation

- **Research Questions Answered:** SQ1 & SQ2
- **Research Methods:** Literature Review, and Interviews.
- **Research Purpose:** The initial investigation phase addressed the first two sub-research questions. The first question is designed to establish a foundational understanding of the current building practices in the Netherlands. This involves delving into the literature to identify different building processes employed in the Netherlands and conducting an exploratory interview with an industry professional to map out the current landscape.

  The second question examines the main stakeholders involved in the decision-making process. A literature review was conducted to identify the relevant stakeholders, followed by semi-structured interviews to explore the various actors and their roles in material selection for architectural and structural elements. This was accomplished through interviews with architects and structural engineers.

2.1.2 Phase 2 - In-Depth Exploration

- **Research Questions Answered** :SQ3 & SQ4
- **Research Methods:** Literature Review and Interviews
- **Research Purpose:** Building upon the foundational understanding from Phase 1, the in-depth exploration phase delves deeper into the design process. Initially, a literature review was conducted to identify potential barriers in the material selection process. Following this, semi-structured interviews were conducted to identify the stages at which decisions are made, as well as to validate the barriers encountered during the material selection process. This approach ensured a comprehensive understanding of the challenges and structure of decision making involved in the design process. This phase enriches our understanding and prepares us for the practical application in the next phase.

2.1.3 Phase 3 - Development and Validation

- **Research Questions Answered:** SQ5
- **Research Methods:** Recommendations Development and Interviews
- **Research Purpose:** In the final phase, the research addresses the fifth sub-research question. The development and validation phase transitions the research from theoretical understanding and exploration to the creation of practical solutions. Recommendations are formulated through a rigorous analysis of the data collected from both literature reviews and interviews. To ensure the practicality and effectiveness of these strategies, further validation is conducted through additional interviews and feedback sessions with industry professionals. This step helps refine and confirm the applicability of the recommendations in real-world scenarios, ensuring the developed solution is both practical and aligned with industry needs.

2.2 Data Collection

Data collection for this research was conducted using two primary methods: literature review and semi-structured interviews. These methods were selected to provide a comprehensive understanding of the research topic and to address the research questions effectively.

2.2.1 Literature Review

The literature review employed a narrative approach to establish the theoretical context and identify existing knowledge and gaps in the field of material selection and emission reduction in construction. A narrative review synthesizes information from various studies that have a common theme to synthesize a comprehensive overview of the topic (Popay et al., 2006).

The process involved sourcing academic journals, industry reports, books, and relevant online resources. Databases such as Google Scholar, JSTOR, ResearchGate, ScienceDirect, and TUDelft Repository were primarily used to source relevant literature. Sources were selected based on their relevance, credibility, and publication date. The literature review focused on key themes such as current building practices in the Netherlands, decision-making processes in material selection, stakeholders involved, and barriers to emission reduction in material selection.

2.2.2 Interviews

Interviews were a crucial part of the data gathering process of the research. Exploratory interviews were conducted initially to understand the current scenario in the building process. Later on, detailed interviews were conducted to delve into the decision-making process during the design phases and to identify the prevalent barriers affecting the projects. Finally, validation interviews were conducted with professionals in the field who have had extensive years of experience in their areas of expertise.

Interviews are a crucial method for collecting qualitative data, offering insights into participants' experiences, perspectives, and the context of their decisions. Different types of interviews include structured, semi-structured, and unstructured interviews, each with its unique benefits and applications (Alsaawi, 2014). Semi-structured interviews are one of the most commonly used interview methods due to their versatility and flexibility (DiCicco-Bloom & Crabtree, 2006). This method combines elements of both structured and unstructured interviews, using a guiding framework of questions aimed at addressing the main objectives. This allows for flexibility and enables the interviewer to follow the respondent's lead and explore topics in depth (Rubin & Rubin, 2011). This method is particularly effective in understanding complex decision-making processes and identifying barriers in material selection.

The candidates for the interviews were selected based on their experience, expertise, and involvement in the decision-making process. All the interviewees are key actors who have a significant influence on the material selection process.

Through the exploratory interview with a project manager, the aim was to gain a holistic view of the building process employed by Royal HaskoningDHV and to identify the currently used process. The semi-structured interviews conducted later aimed at gaining insights into when and how decisions for material selection are made in their respective fields or areas of work, as well as what hinders the process from selecting emission-friendly materials. This was conducted with professionals employed under Royal HaskoningDHV as well as with architects and structural engineers from firms outside Royal HaskoningDHV to gain a much broader implication. Later on, the validation interviews were conducted to validate and provide feedback on the recommendations developed. The aim was to gain insights from their experience on the validity and practicality of the results and the recommendations proposed. More details regarding the types of questions can be found in the interview procedure in section 7.1 as well as in the appendix.

2.2.3 Data Analysis

The analysis of interview data followed a structured approach to ensure comprehensive and accurate interpretation. Although no specific qualitative data analysis software was used, Mendeley, a reference manager software, was utilized to organize and categorize the data. Each transcript was reviewed, and relevant sections were tagged according to the identified themes. Tags were created for each major topic, allowing for efficient categorization and retrieval of data related to specific aspects of the research. This process enabled the organization of the data into coherent categories representing key themes such as emission reduction, material selection, stakeholders, and barriers.

2.3 Structure of the report

Chapter 1 - Introduction

This section sets the direction for the research, outlining the current issues or main issues that need to be addressed. It provides a holistic view of the issue and its effects, as well as details the problem definition, objective, and the main questions that this study aims to answer.

Chapter 2 - Research Methodology

This section outlines the methods and approaches the research utilized to obtain its results. Various qualitative approaches such as literature study and interviews were primarily employed. It also depicts the design of the study and details how data was collected and analyzed, including descriptions of the tools and processes used.

Chapter 3 - Literature Review

This chapter provides a detailed review of the currently available and used building processes, barriers identified, and the stakeholders involved during the decision-making process. It synthesizes previous research findings and identifies gaps.

Chapter 4 - Interview Results and Analysis

The findings from stakeholder interviews are presented and analyzed in this section. The interviews were conducted with stakeholders identified earlier, providing a clear understanding of the practical aspects of the decision-making process. A timeline of when critical decisions occurred was developed, and major barriers hindering the decision-making for material selection were identified.

Chapter 5 - Summary of Barriers

This section provides a detailed explanation of all the barriers identified from both the literature and practical aspects. It explains why these barriers are a concern.

Chapter 6 - Recommendations

Based on the research findings, this section offers practical recommendations for improving processes or practices in the area under study. It showcases strategies developed to overcome and mitigate the barriers identified earlier, focusing on issues such as early decision-making, knowledge gaps, and transparency among the multidisciplinary team.

Chapter 7 - Expert Validation

The recommendations developed were validated in this section. Experts with over three decades of experience were interviewed to provide feedback on the practical application of the research. Their insights ensured the relevance and applicability of the findings and recommendations. This validation process helped refine the recommendations, making them grounded in real-world contexts.

Chapter 8 - Discussion

This section provides in-depth insights and connections between the broader context and currently available literature. It interprets key findings and insights regarding the material selection process and the effect of the research on the overall process. Additionally, it highlights the limitations or constraints identified during the research.

Chapter 9 - Conclusion and Future Research

This section provides a final overview of all the findings and aims to answer the main research question and sub-questions. It includes implementation strategies and recommendations for Royal HaskoningDHV to follow. It also suggests areas for future research to further explore and address remaining gaps.

Chapter 3

Literature Review

3.1 Building process in the Netherlands

A construction project is a complex and intricate process involving various interlinking elements. Therefore, a well-structured building process not only guides the project from conception to completion but also ensures optimal resource utilization, minimizing waste and reducing costs. An appropriately detailed construction plan, considering these factors, significantly impacts the efficiency and, in some cases, the feasibility of the entire construction project (Lapidus & Abramov, 2018).

1. **Basic Design Cycle**

   The basic design draws from the methods of Professors Roozenburg and Eekels from the Faculty of Industrial Design at TuDelft (Hertogh et al., 2019). It involves a set of activities and phases within the elementary design cycle. This cycle is divided into five stages, with each containing activities repeated in every phase. A flow diagram visually represents the activities within each stage as follows:

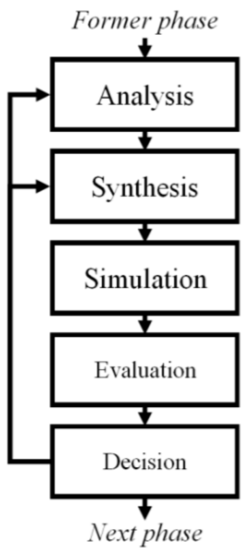

Figure 3.1: Basic Design activities (Hertogh et al., 2019)

- **Analysis**: During the Analysis phase the main aims are described, the problems are defined, objectives are set, and the project's initial targets and criteria are established.
- **Synthesis**: In the Synthesis phase, potential answers to the issue are developed.
- **Simulation**: The Simulation phase involves verifying whether these solutions fulfill the established criteria, and discarding those that do not meet the requirements are put aside.
- **Evaluation**: Solutions that pass the simulation stage are then assessed and ranked during the Evaluation phase.
- **Decision**: Eventually the best solution is chosen in the Decision phase.

The phases in Baisc Design Plan

The Basic Design Plan (BDP) incorporates a 'construction cycle' through five distinct phases, covering the project from inception to completion. Each phase is further broken down into sub-stages for detailed development:

Table 3.1: Basic Design Cycle Hertogh et al. (2019)

Phase	Further Classification of the Phases
Initiation phase	• Initiative • Feasibility study • Project definition
Preparation phase	• Sketch design • Preliminary Design • Definite design • Detailed design (specifications/contracting/-price)
Realization phase	• Work preparation • Execution • Delivery
Use phase	• Operation, maintenance and renovation
Demolition/reuse phase	• Demolition/reuse

Each sub-phase within the design phase goes through the basic cycle (analysis-synthesis-simulation-evaluation-decision). This structure allows for iterative refinement at every level (Hertogh et al., 2019). The process begins with a macro approach, considering all project elements broadly with only general ideas and limited data. As the project moves through various design phases, it transitions to a meso level, focusing on more detailed aspects such as calculations and more precise layouts. Finally, in the micro phase, finer details are refined and finalized, ensuring thorough examination and completion of all project elements (Hertogh et al., 2019).

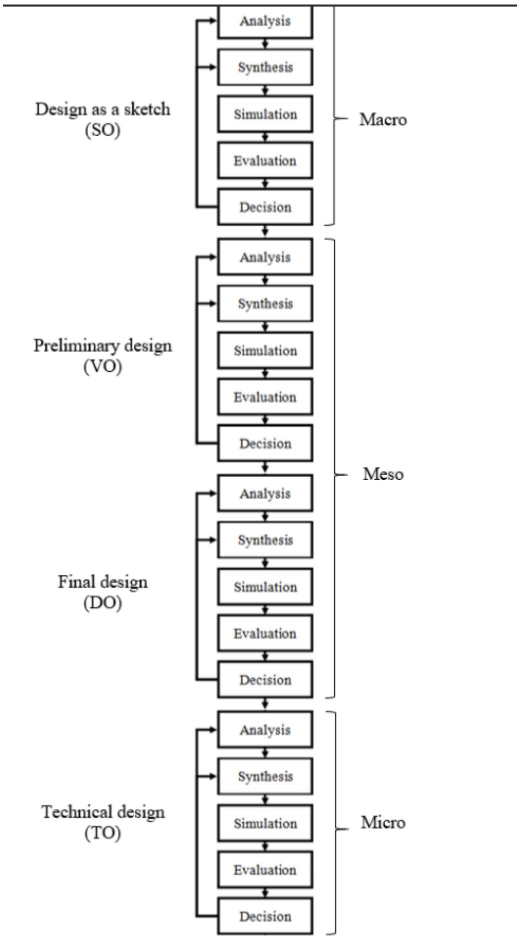

Figure 3.2: Basic Design Cycle- Macro-Micro

2. DNR-STB

   The DNR-STB, developed by the Dutch Architects Association (BNA) (Architectenbureaus, 2020), outlines essential criteria and activities for construction projects, delineating deliverables through a structured framework. It operates alongside DNR a standard condition for consultants and clients across ten comprehensive building phases ensuring a systematic approach from project inception to completion. These phases encompass initial assessments like feasibility studies and location examinations, as well as detailed phases such as design, engineering, and technical specification development, ultimately guiding the project through to its utilization phase.

Figure 3.3: Detail DNR-STB

These phases encompass initial assessments like feasibility studies and location examinations, as well as detailed phases such as design and engineering, and technical specification development, ultimately guiding the project through to its utilization phase. Table 2 shows the design phase and its contents within the DNR-STB

Table 3.2: DNR-STB-design phases

Phase	Goal	Deliverable	Activities
3. Schematic Design	Develop the project's initial concept	Conceptual solution, Basic design outline, Initial function allocation	Develop an urban plan, and investigate the installation and construction design principles
4. Pre Design	Generate a comprehensive concept of the structure	Conceptual design, Key structural elements, Architectural concept	Draft an urban concept, assess initial structural and systems design approaches
5. Definitive Design	Finalize the design with comprehensive decisions	Detailed integral design	Design the functional arrangement and architectural concept, conclude the urban concept, layout, and material selection, and unify the architectural, structural, and systems designs
6. Technical Design	Elaborate the design details technically	Detailed technical design	Produce detailed design drawings, specify the structural and systems design details, conduct detailed systems calculations, and generate systems design drawings

3. **NEN 2574**

The NEN 2574 standard, developed in 1993, provides a foundational guideline for building processes in the Netherlands. It establishes rules for classifying information on drawings across different construction stages through follow-up lists, providing clarity for professionals involved in drafting and planning. who will gain explicit clarity about the requirements that are placed on the content of drawings. NEN 2574 is formulated as a framework. This means that this standard stipulates that agreements must be made with regard to the phases to be declared applicable and the package of drawings (NEN, 1993).

NEN 2574 consists of eleven phases

Figure 3.4: Detailed NEN 2574, developed from NEN (1993)

In the case of NEN 2574, the design and engineering phase begins from phase 4 Schematic Design (SO) to phase 6 Definitive Design (DO). Below is a detailed table about the different design and engineering phases.

Table 3.3: NEN 2574-design phases

Phase	Objective	Strategy	Execution Blueprint
4. Schematic Design	Establish the project's framework	Sketch the project's design	Formulate early functional plans and initial design drafts.
5. Preliminary Design	Identify design possibilities	Create alternatives across all disciplines	Create the operational and technical plans, early financial outlines, and preliminary sketches
6. Definitive Design	Refine selected design options	Finalize the ultimate design choice	Construct the design to meet criteria and governmental guidelines.

3.2 Foreign building practices

To provide a broader perspective and enrich the analysis, it is essential to consider both local and international building practices. While the focus remains on the methodologies and standards used in the Netherlands, examining foreign frameworks, such as the RIBA Plan of Work developed by the Royal Institute of British Architects, offers valuable insights. This approach allows for a comparison of practices to understand the similarities and differences between what is done in the Netherlands and what is implemented abroad. By doing so, we can gain a more comprehensive understanding of how local and international approaches align or diverge.

1. **RIBA Plan of work**

The RIBA Plan of Work, proposed by the Royal Institute of British Architects, originally a matrix, evolved into a detailed framework guiding the design and construction process. The RIBA Plan of Work organises the process of briefing, designing, constructing, and operating building projects into eight stages and explains the stage outcomes and core tasks required at each stage royal-institute-of-british-architects-2024.

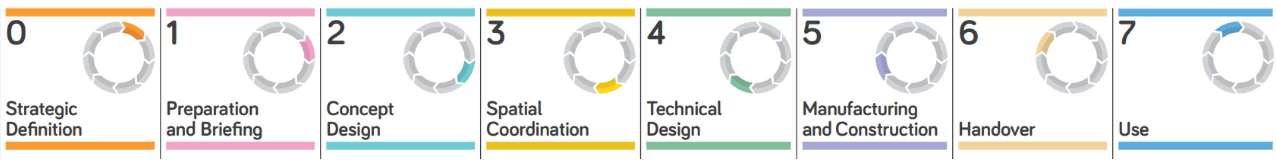

Figure 3.5: RIBA Plan of Work, Architects (2024)

The crucial phases extend from one to six, beginning with project initiation (phase zero) and extending to future usage considerations (phase 7). The plan emphasizes decision-making from outline needs through descriptive, prescriptive detailed solutions, integrating client requirements, design specification, and final product selection, ensuring comprehensive project development and execution.

Outline

In the RIBA Plan of Work, the 'Outline' phase represents the initial stage where the client's needs, ambitions, and design intents for the project are captured. Initially broad and conceptual, these requirements serve as a foundation for more detailed planning. As the project progresses, these initial ideas are refined into specific criteria and detailed requirements for systems and products, guiding the design and construction process.

Descriptive

In the Descriptive phase of the RIBA Plan of Work, the specification delineates the project's overall performance, addressing criteria like fire safety, thermal efficiency, acoustics, structural integrity, and durability. It aligns with designated design standards, guiding specialist subcontractors through to completion, ensuring all specified performance and aesthetic requirements set during planning are met.

Prescriptive

Prescriptive design delves deeply into the selection of products that match the profile developed in the descriptive phase. Initially, the project focuses on broad, descriptive ideas; however, as the design process progresses, these evolve into specific, prescriptive criteria. This phase ensures the detailed solutions adhere to the overall performance criteria set by the client's brief and earlier specifications.

3.3 Barriers Identified

This section presents a literature review exploring the barriers impacting the decision-making process for material selection aimed at reducing emissions. The research has identified several barriers that influence the selection of materials in emission-friendly construction. Addressing these barriers is crucial to facilitating a more sustainable material selection process. These barriers were identified through a narrative literature review, using keywords such as 'emission-friendly material selection,' 'decision making,' 'embodied carbon barriers,' and 'high carbon materials.'

3.3.1 Climatic conditions

Climatic conditions significantly impact the selection of building materials, as they directly affect a material's effectiveness and durability in different environments. According to Kanniyapan, Mohammad, Nesan, Mohammed and Ganisen (2015), designers must prioritize climatic considerations to prevent the early deterioration of buildings. This involves assessing the average yearly temperature, daylight availability, precipitation likelihood, and ventilation needs specific to an area (Ilaan, 2022). Certain materials may underperform in particular climates even though they function well in another location due to climatic circumstances (Kanniyapan et al., 2015).

In the Netherlands, known for its extreme windy conditions due to its flat landscape and proximity to the North Sea, strong winds are a frequent occurrence (Atlas, 2024). Additionally, the country experiences frequent and heavy rainfall, with an average annual precipitation of around 778 mm (Statista, 2024). Building components in the Netherlands should be able to withstand high altitudes of wind and occasional storms. Therefore, materials that are able to withstand wind uplifts, heavy pressure, and seasonal temperature changes are crucial. Choosing materials inadequately suited to the local climate can significantly increase maintenance efforts. de Silva, Dulaimi, Ling and Ofori (2004) also supports this and explains that the selection of materials in a certain location, is affected by the climatic conditions present. Furthermore, Al-Hammad, Assaf and Al-Shihah (1997) highlights that inadequate material selection can lead to higher maintenance, cleaning, and repairing efforts due to the accumulation of moisture, water, or dust.

3.3.2 Economic factors

Economic conditions significantly influence the selection of materials for construction. This is evident in the varying inclination towards sustainable materials between developed and developing countries, as demonstrated in studies by Chacón, Chen Austin and Castaño (2022). Kanniyapan et al. (2015) in his research, emphasized that economic factors are crucial when selecting facade systems. Arguing for a material economy approach—selecting materials that offer the best performance for the least initial and lifecycle costs. Chew, De Silva and Tan (2004) further supports this by highlighting the common focus on initial costs by designers and clients, which may not always present the most economical solution due to the higher maintenance needs of cheaper materials or materials that emit lesser emissions but might require more maintenance as well. Therefore, it is clear that economic criteria must be carefully considered during the material selection process.

In the Netherlands, the economic climate plays a pivotal role. The Dutch economy is expected to grow in 2024 after recovering from inflation, with GDP growth projected at 0.8% (European Commission, 2024). Inflation is expected to decrease to around 2.5% in 2024, alleviating some financial pressures (European Commission, 2024). These economic conditions impact the construction industry significantly, influencing the cost and availability of building materials.

Similarly, the concept of Net Zero Energy Buildings (NZEB) has been quickly adopted in developed countries, contrasting with the challenges faced in developing countries. This has led to Feng et al. (2019) concluding that economic barriers are the primary limitation for NZEB implementation in developing areas, suggesting a focus on passive approaches and solutions requiring low initial capital in developing countries. Mohammadi et al. (2022) in his work on material selection for facades underscores the economic considerations in the process. Their findings which were influenced by the interviewees' perspectives which were shaped by Iran's economic condition at that time, echo the sentiment that economic factors play a pivotal role in material selection for construction projects.

3.3.3 Regulatory compliance

Regulatory compliance is a critical aspect of the construction industry, blending legal requirements with ethical construction practices. It encompasses a wide array of areas including worker safety, material quality, and the legality of construction contracts. Local building codes often specify which materials can be used; for instance, certain types of paints may be restricted due to some of their impact (van Hoof, 2021). Keeping up-to-date with these regulations is crucial to avoid legal and financial repercussions. Additionally, compliance impacts the usability of low-emission materials such as reusable ones (Rakhshan, Morel, Alaka & Charef, 2020). Sometimes, these materials cannot be used not due to their performance but because they lack necessary certifications related to fire safety or other regulatory standards as well (van Hoof, 2021). This issue extends to cost-effective green buildings that, despite their low emissions, cannot be implemented due to failing to meet certain regulatory certifications (Yang & Ogunkah, 2013).

As projects grow in complexity, the importance of thorough compliance becomes even more evident, influencing everything from safety measures to material choices. It is essential for companies to manage actively and stay informed about these regulations.

Milieuprestatie-gebouwen (MPG)

In response to the urgent need to align construction practices with the Netherlands' future sustainability goals, the government has implemented a set of environmental assessment criteria known as the Milieuprestatie Gebouwen (MPG) (voor Ondernemend Nederland, 2024). Designed to evaluate the environmental impact of new buildings and major renovations, the MPG framework quantitatively assesses the environmental footprint of construction materials and processes across their lifecycle through Life Cycle Assessment (LCA). This initiative aims to reduce the overall environmental impact and emissions associated with a building. The regulation mandates a comprehensive assessment of construction materials' environmental performance, utilizing multiple indicators. These indicators, covering aspects like global warming potential, resource depletion, and toxicity, are synthesized into a singular metric known as the shadow price. With a maximum allowable MPG value set at 1.0 where a lower score indicates lesser environmental impact, the regulation encourages the construction industry to adopt practices that significantly reduce environmental harm (voor Ondernemend Nederland, 2024). This shadow price, reflecting the cumulative environmental impact, facilitates informed decision-making in material selection. The MPG, therefore, stands as a significant factor in the construction process, encouraging sustainable practices by incorporating comprehensive environmental considerations into the very fabric of construction projects.

One major issue identified is the lack of comprehensive information in the current databases used for MPG assessments. Research has shown that existing databases often lack the detailed and diverse data necessary to make fully informed decisions about sustainable materials (Springvloed et al., 2021). The study also highlighted that the MPG tool relies heavily on data from traditional construction elements and existing climate databases, which do not account for innovative materials and methods (Springvloed et al., 2021). This limitation means that new and potentially more sustainable materials are not adequately measured for their sustainability.

3.3.4 Early Decision-Making in Design Process

One significant barrier in the material selection process for emission-free construction is the lack of early decision-making in the project. Making decisions early in the project facilitates cost-effective choices, leading to significant savings in time and money (Schade, Olofsson & Schreyer, 2011). However, in practice, such critical decisions are often delayed, which reduces the opportunity for optimization and innovation. As the project moves forward through the different phases, decisions taken late become more difficult and costlier to implement. This highlights the importance of focusing on the early design phase, where decisions significantly affect the project's final outcomes and performance (Bragança et al., 2014). It also allows the design team more freedom to innovate, as there are more possibilities available in the initial stages (Schade et al., 2011). Below is a graph depicting the possible impact of making decisions early in the building process.

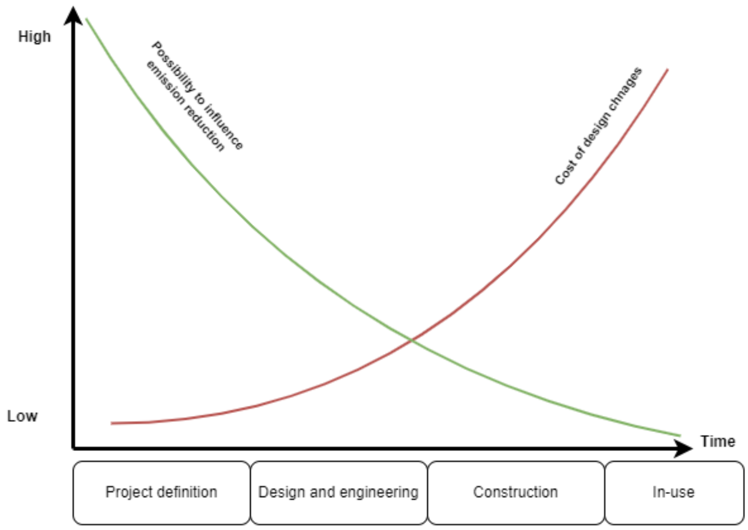

Figure 3.6: The possibility of influencing change and cost, inspired from Bragança et al. (2014); Mathern (2019)

Despite the clear benefits of early decision-making, it's often not practiced. The necessity for important choices to be made early in the project is apparent and often highlighted (Bragança et al., 2014). This is supported by research findings that shifted the main focus from detailed design to early design phases, as the majority of decisions severely impacting the project were made there (Schade et al., 2011). The reasons for the lack of early decision making are explored in the subsections below.

Lack of Knowledge, Expertise, and Reliable Information

Despite the Netherlands' strong commitment to reducing emissions and setting future goals, there is a notable gap in knowledge and expertise regarding emission friendly materials, creating a barrier to their widespread adoption in construction. This deficiency is particularly problematic as the decision-making process in construction heavily relies on the accuracy of data and a thorough understanding of emission-friendly products (Sivasubramanian & Lee, 2022).

There is an evident lack of technical knowledge about material properties, performance, and characteristics such as emission footprints. This can lead to poor material decisions that do not meet the project's requirements or expectations. Giesekam, Barrett, Taylor and Owen (2014) emphasize that actors involved should be proficient in the latest advancements in material science; otherwise, they risk continuing the use of outdated or less efficient materials. Engineers and architects involved in the decision-making process might prefer familiar materials over potentially better alternatives due to their comfort and experience with those materials. This preference can hinder innovation and the adoption of more suitable options (Harty, 2008).

In addition to knowledge gaps, the lack of reliable and comprehensive data on material properties, costs, and environmental impacts presents substantial challenges for decision-makers. Incomplete or inaccurate information can lead to poor material choices that do not align with the project's performance, cost, or emission goals (Asif, Muneer & Kelley, 2007). Although early decision-making is recognized as beneficial (Mathern, 2019), the lack of proper knowledge during the early stages can hinder the selection process. Mathern (2019) highlights the need to avoid making decisions with limited knowledge in the early phase and stresses that engineers need the right tools and abilities to make informed choices. Ogunkah and Yang (2012) note that only a limited number of professionals are currently capable of making decisions related to low-cost green building materials. As global standards continue to evolve, concerns over data reliability grow, here (Sivasubramanian & Lee, 2022) emphasize the need for extensive additional knowledge about various sustainable products, software, and product evaluation methods to make precise decisions.

Inadequate Early Project-Specific Information

During the initial phases of a project, when the requirements and ambitions are still shaping, there is often a notable gap in reliable data regarding the project. This inadequate availability of detailed project-specific information at the early stages significantly affects the ability of the project team to make impactful decisions regarding material selection. Jin et al. (2014) talks about the difficulty in accurately estimating construction costs at the early stages due to limited information. They mention various factors that limit early data issues and categorize them into numerical and categorical variables.

Table 3.4: Description and Types of Variables (Jin et al., 2014)

Description	Type
Floor area ratio	Numerical
Number of households	Numerical
Number of floors	Numerical
Number of elevators	Numerical
Apartment type	Categorical
Hallway type (stairway or corridor)	Categorical
Foundation system (pile or mat+pile)	Categorical
Roof type (flat, inclined, or gable)	Categorical
Structure type (RC wall)	Categorical
Construction cost	Numerical

The lack of comprehensive data at the beginning of a project regarding feasible requirements, site-specific factors, material performance in specific contexts, and other critical elements complicates the selection of sustainable materials and other crucial decisions. However, as seen in Section 3.3.4, making such critical decisions early enables more productive and efficient outcomes. Hester et al. (2018) highlight the benefits of conducting a proper Life Cycle Assessment (LCA) at the beginning of a project. They point out the current issue of LCAs typically being conducted only in the later stages of a project when the design and data are more certain. Aghimien, Aigbavboa, Oke and Setati (2018) mentions the challenges of front-end loading in construction projects, identifying unreliable early-stage information and the need for structured project teams as major obstacles. This is also prevalent in identifying cost or budget estimates. A definite cost estimate during the early stages is difficult due to unexpected cost changes stemming from unidentified uncertainties, which may remain until the definite design stages (Treasury, 2015).

3.3.5 Type of contract

Although the DNR-STB outlines preset phases and steps for the building process, the type of contract employed can significantly influence and shape the entire construction sequence (Weller, 2016). This impact is underscored in Weller's research, which compares the effects of different standard contracts, on project phasing and the specifics of included phases. Weller (2016)'s study reveals that variations in contracts affect how deliverables are defined within each phase, altering, emission requirements and task assignments. The choice of contract not only dictates the division of tasks and the level of control during each phase, crucially influencing project control. Similarly, the type of contract determines when certain parties, such as the contractor, are involved in a project (Song, Mohamed & AbouRizk, 2009). Contracts that involve the contractor early offer opportunities for better cooperation among the design teams and lead to better project outcomes (Rahman & Alhassan, 2012). Conversely, traditional projects such as design-bid-build involve the contractor later, resulting in missed practical considerations that the contractor could have provided (Song et al., 2009).

3.3.6 Stakeholder Conflicts

When working with multiple disciplines, the likelihood of encountering problems increases significantly. The decision-making process for material selection involves various stakeholders from multiple disciplines, making it challenging to reach a consensus without proper collaboration. Garmston et al. (2012) details the difficulties encountered when working within such diverse groups. Effective collaboration among team members requires clear communication, cooperation, and the ability to work together seamlessly. Despite interprofessional teamwork being extensively discussed in literatures and its recognized potential to deliver high-quality services to clients, the probability of encountering interpersonal issues is notably high (Guevara & Boyer, 1981).

Anthony, Militaru and Mattar (2018) in their research on significant factors causing errors in design highlighted the lack of coordination as a significant barrier. The decision-making process during material selection is intricate, involving many design phases and participants, including clients, design teams, contractors, and manufacturers. Reaching consensus in such a multidisciplinary team is often filled with difficulties (Garmston et al., 2012). Each of them will have different objectives that they prefer to prioritise such as cost reduction, performance optimization, and profit or sustainability goals, leading to disagreements and delays in decision-making (Gambo & Taveter, 2021). When stakeholders cannot agree on the material selection criteria or the final choice, the decision-making process can become stalled, resulting in missed opportunities for selecting the most suitable materials (Gambo & Taveter, 2021).

3.4 Stakeholder Perspective in Material Selection Decision-Making

The decision-making process for material selection in construction projects involves multiple stakeholders with diverse roles, priorities, and influences. Understanding these perspectives is crucial for developing a comprehensive approach to promoting emission-free material choices. This section explores the perspectives of key stakeholders, including clients, architects, structural engineers, and material experts, drawing insights from literature and contractors conducted as part of this research as each of them play an important role in reaching low emission buildings (Chan, Masrom & Yasin, 2022).

3.4.1 Client Perspective

The client plays a central role in setting the sustainability agenda for construction projects, influencing material selection through their goals, budget constraints, and long-term vision (Khahro, Shaikh, Zainun, Sultan & Khahro, 2023b). As the most important stakeholder, the project primarily aims to meet their requirements and ambitions, with their decisions heavily influencing material choices (Adams, Osmani, Thorpe & Hobbs, 2017). The client's background and budget significantly impact these decisions, and their high level of control means any delay in decision-making can negatively affect project timelines and sustainability goals (H. Li, Ng & Skitmore, 2018).

Clients can drive the shift towards sustainable construction by promoting new business models, whole-life thinking, and setting a clear project direction (Adams et al., 2017). Their sustainability ambitions and willingness to invest in green materials are key drivers for selecting emission-friendly materials (Chan et al., 2022). However, clients often prioritize cost and time over environmental factors, tending to choose traditional materials like steel and concrete due to economic considerations (Al-Atesh, Rahmawati, Zawawi & Utomo, 2021). While there is growing awareness of emission reduction, it is not yet a top priority in material selection (S. Li, 2024). Ultimately, clients' decisions significantly impact material selection processes, project outcomes, and the overall emission reduction of construction projects (Roslan, Samsudin & Mohammad, 2022).

3.4.2 Architect Perspective

Architects are an integral part of the design team and are involved in making decisions on material selection. Darko, Zhang and Chan (2017) show that among the stakeholders whose opinions on the drivers for implementing green building practices were studied, architects were the most prominent. The architect primarily deals with decisions regarding facade elements and focuses on the aesthetics of the building. Based on the client's wishes and ambitions, architects work together with the client to achieve the desired outcomes. According to Häkkinen and Belloni (2011), architects play a crucial role in promoting sustainable practices by advocating for the use of eco-friendly materials and designing buildings that minimize environmental impact. Their involvement in the early stages of design is critical to achieving sustainable outcomes (Chan et al., 2022).

A study highlights architects as crucial decision-makers in the material selection process. It emphasizes that material selection in architecture is influenced by numerous factors, not limited to technical properties but also aesthetic, experiential, and contextual aspects (Wastiels & Wouters, 2008), and they strive to choose materials that not only perform well technically but also contribute to the desired aesthetic and sensory experience of the building. A study by Manewa, Siriwardena, Ross and Madanayake (2016) identifies key factors such as environmental performance, health impacts, and lifecycle costs. Architects must weigh these factors against traditional considerations like structural performance and aesthetics.

Akadiri (2015) notes that architects' knowledge of emission-friendly materials significantly influences their specification choices. Similarly Low, Gao and See (2014) mentions that architects are more aware and knowledgeable about low-emission materials and play a pivotal role in educating clients and recommending green materials to them (Blum, Deilmann & Neubauer, 2001). Studies also show that architects often act as mediators in this process, facilitating communication and ensuring that sustainability goals are integrated into the project (Darko et al., 2017).

3.4.3 Structural Engineer Perspective

Structural engineers are a crucial group within the construction industry, significantly impacting material choices (Omar et al., 2023). Structural engineers supervise and collaborate closely with architects and other design team members to balance structural integrity and sustainability goals. However, their main focus remains on the structural properties of materials, such as load-bearing capacity, durability, and resilience to environmental conditions (Mora, 2007). Their technical knowledge enables them to identify and recommend materials that reduce overall carbon emissions in the building while maintaining structural performance (Cabeza, Rincón, Vilariño, Pérez & Castell, 2014). They also promote the use of recycled or reclaimed materials with lower carbon content and innovative construction techniques such as modular construction (Bribián, Capilla & Usón, 2011).

Several factors limit structural engineers from opting for low-emission materials. A significant challenge is balancing cost and environmental benefits, as cost is a key factor in material selection. Structural engineers aim to find a balance between cost-effectiveness and environmental benefits, ensuring sustainable materials are feasible within the project budget and timeline (Rettinger & Meyer, 2023). Structural engineers need to ensure that the selected materials comply with relevant building codes and standards, adhering to regulations related to structural safety, environmental impact, and sustainability (Ding, 2008). They ensure that selected materials comply with relevant building codes and standards, adhering to regulations related to structural safety, environmental impact, and sustainability (Chaudhary & Piracha, 2013). Another common factor hindering the use of sustainable materials is the familiarity and level of information engineers have about these materials. Based on this, research has shown that structural engineers tend to prefer steel over new materials (Chan et al., 2022).

3.4.4 Government and Regulatory Perspective

Government and regulatory bodies play a crucial role in shaping material selection decisions. These decisions are driven by a combination of environmental policies, building codes, certifications, and incentives aimed at reducing carbon footprints and promoting sustainability. For instance, in the Netherlands, the government has established policies aiming for a substantial reduction in greenhouse gas emissions and a 50 percent reduction in the use of primary raw materials by 2030 (Planbureau voor de Leefomgeving, 2023).Additionally, there are plans for a transition to climate neutrality by 2050 (Ministerie van Economische Zaken, 2020). Regulatory compliance is another crucial factor. The client, contractor, and design teams must ensure that the building adheres to local and international building codes and regulations, which are increasingly emphasizing sustainability and low emissions. Building codes and standards are fundamental tools used by governments to enforce sustainable construction practices. The European Union's regulation called REACH (Registration, Evaluation, Authorisation, and Restriction of Chemicals) aims to control the use of hazardous substances in construction materials (*Understanding REACH*, 2024).

Financial incentives are instrumental in promoting the use of sustainable building materials. Grants and subsidies provide direct financial support for the research and development of new sustainable materials and technologies. The EU has several grants and fund programs that aim to promote innovation and ideas that mitigate carbon emissions (European Horizon, 2024). Similarly, green loans and specialized financing options further support sustainable construction projects, incentivizing more people to undertake emission-free projects (World Bank, 2024).

Mandatory requirements set by governments ensure that only materials meeting specific sustainability criteria are used in construction. In the Netherlands, the MPG regulation set by the government aims to limit and calculate the carbon footprint in a building, aiming to reduce the environmental impact of buildings (voor Ondernemend Nederland, 2024). Minimum performance standards, such as those for insulation effectiveness or material durability, are essential for maintaining quality and sustainability (*Directive - EU - 2024/1275 - EN - EUR-Lex*, 2024). Building codes and standards set by local authorities dictate the minimum requirements for fire safety, energy efficiency, and environmental sustainability. These regulations often specify the use of certain materials or establish performance criteria that materials must meet. Certification requirements, such as those mandated by LEED or BREEAM, further ensure that building projects comply with established sustainability standards, promoting the use of certified sustainable materials (BREEAM, 2024; U.S. Green Building Council, 2024). Q. Xu, Liu, Chen and Lou (2023) demonstrated that government subsidies and carbon tax penalties are crucial in motivating manufacturers and research institutes to develop and adopt low-carbon materials, suggesting that policy instruments can effectively shift industry behaviors. Additionally, government incentives and rebates for green buildings can make these materials more financially viable (Giesekam et al., 2014).

3.4.5 Contractor Perspective

Contractors play a significant role in the material selection process and have substantial influence when they are involved (Chan et al., 2022). They are responsible for procuring and installing the chosen materials, providing valuable insights into practical aspects such as availability, lead times, and ease of installation. While some studies indicate that contractors primarily focus on their profit and may steer the decision-making process towards their own needs (Salam, Forsythe, Killen & Abd Al Salam, 2019), the concept of Contractor Green Construction Capabilities (CGCC) is central here. CGCC involves integrating sustainable materials and practices into building construction (Emre Ilgın, Soikkeli, Koponen & Karjalainen, 2022). Focusing on CGCC motivate contractors through the economic benefits of emission-friendly construction, such as reduced material costs and waste minimization. Using emission-friendly materials also makes them more competitive in the market (Gu, Guo, Peng & Wang, 2023).

Another important criterion for contractors is meeting the client's expectations and achieving the goals set in the contract. Effective communication between the contractor and client is essential to align these goals (Gu et al., 2023). Contractors are also influenced by regulatory requirements set by the governments (Omar et al., 2023).

While low-emission materials are beneficial, other factors must be considered, such as the availability and supply chain reliability of sustainable materials. Contractors need materials that are practical to work with and integrate well with existing construction processes (Emre Ilgın et al., 2022). However, their decision-making is often based on previous experience such as with concrete or steel rather than a thorough cost analysis of alternatives. This cognitive bias hinders the adoption of emission-friendly materials in buildings (Hemström, Gustavsson & Mahapatra, 2017). The cost of sustainable materials can also fluctuate, adding uncertainty to project budgets (Zuo & Zhao, 2014).

3.4.6 Sustainability consultant Perspective

Sustainability consultants or experts in sustainability, as discussed by Shdifat, Jalón, Puertas and Chiachío (2023), play an increasingly critical role in guiding material selection towards more environmentally friendly options in construction projects. Their expertise in sustainable design and deep understanding of the environmental impacts associated with various materials enable them to significantly influence decision-making (Siddhpura & Siddhpura, 2024). Abouhelal, Kamel and Bassioni (2023) emphasizes the importance of these experts in identifying sustainable building materials that minimize environmental impact, reduce natural resource consumption, and enhance building performance. These consultants advocate for the use of materials with lower embodied energy, reduced carbon footprints, and sustainable sourcing (Abera, 2024). To achieve this, sustainability consultants utilize various tools, such as multicriteria decision-making approaches (MCDA), to rank and select sustainable materials based on multiple performance criteria, ensuring a holistic approach to sustainability in construction projects. They also frequently perform lifecycle assessments (LCA) to evaluate the environmental impact of materials over the entire lifecycle of a building, from extraction and manufacturing to use and disposal (Hussain & Sheikh, 2023).

Furthermore, sustainability consultants are crucial in navigating the complex landscape of green building certifications, such as LEED and BREEAM, which often require specific material choices to meet stringent environmental criteria (Hussain & Sheikh, 2023). Their knowledge of these certification systems enables them to guide project teams in selecting materials that not only meet sustainability standards but also contribute to achieving higher certification levels. By providing comprehensive analysis, they help stakeholders make informed decisions that align with long-term sustainability goals. For instance, they may recommend alternatives to traditional materials like concrete and steel, known for their high carbon emissions, in favor of materials such as timber or low-carbon concrete, which offer similar performance with reduced environmental impact (Abera, 2024). Their expertise bridges the gap between designers and decision-makers, facilitating the selection of materials that maximize sustainability throughout the building's lifecycle (Abouhelal et al., 2023). Ultimately, their role is essential in driving the construction industry towards more sustainable and environmentally friendly practices

Chapter 4

Interview results and analysis

To gain comprehensive insights into the decision-making processes and barriers associated with material selection in building projects, an exploratory interview and a series of semi-structured interviews were conducted. These interviews aimed to capture the current scenario, experiences, and perspectives of various stakeholders involved in the construction industry. The interviews were conducted both online and offline, with each interview being recorded with prior consent from the participant. Each interview lasted approximately 45-60 minutes. In addition to the recordings, notes were taken during the interviews when key points were mentioned.

4.1 Participant Overview

Respondents' Backgrounds

As explained in section 3.4, the respondents were chosen based on their involvement in the decision making process in the material section process. Interviews were conducted with a diverse group of professionals, including architects, structural engineers, MEP (Mechanical, Electrical, and Plumbing) engineers, and sustainability consultants. To maintain anonymity, each participant was assigned a unique code. The table below provides an overview of the interview participants:

Table 4.1: Interviewee Codes and Positions

Associated Code	Position
A1	Architect
A2	Architect
A3	Architect
A4	Architect
S1	Structural Engineer
S2	Structural Engineer
S3	Structural Engineer
S4	Structural Engineer
S5	Structural Engineer
S6	Structural Engineer
X1	Expert on Material Properties
P1	Project Manager
SC1	Sustainability Consultant

Table 4.1: Interviewee Codes and Positions (continued)

Associated Code	Position
SC2	Sustainability Consultant
SC3	Sustainability Consultant
ME1	MEP Engineer

4.2 Current Building Process

As explained within section 3.1, the building processes currently available in the Netherlands are well-detailed and structured, typically following a similar, well-defined progression through various phases. Further insights were gained from an exploratory interview with a project manager PM1, who has extensive industry experience. This interview highlighted the DNR-STB as the most commonly used and prevalent building process. This preference for DNR-STB was corroborated by other interviews as well.

Although the general consensus from the interviews acknowledged the DNR-STB, there were instances where projects did not follow a set theoretical process due to project constraints. However, the specific steps or phases of DNR-STB were quite evident in these projects as well. This is supported by A1:

> *" I have used a process of taking reference from DNR, but it has a different type of contract, so that's the reason we have not gone in for the typical DNR, but we do use it as a frame of reference for the project."*

To identify when key decisions are made, this research utilized a design process flowchart developed by Royal HaskoningDHV. This flowchart, documented in detail in the appendix B.1., highlights critical decision points that influence the overall project outcome.

4.3 Timing and Context of Material Selection Decisions

The timing and context in which material selection decisions are made play a critical role in the overall emission reduction potential of a construction project. According to X. Xu and Deng (2022), the timing of these decisions is crucial for project success and cost optimization. The point in the project lifecycle at which these decisions are made, and the factors considered during the selection process, can significantly influence the environmental impact of the chosen building materials.

The DNR-STB process includes 10 well-detailed steps, ranging from the initial initiative to the usage phase. Interviews with relevant stakeholders provided insights into how and when material selection decisions are made. The results and data obtained from these interviews are detailed in the following sections.

4.3.1 Material selection for structural elements

As detailed in section 1.2.1 structural elements are a crucial aspect of the building process, as the material selection decisions of these elements directly impact the stability, durability, and environmental footprint of the construction project. Therefore interviews with structural engineers and sustainability consultants provided valuable insights into the timing and context of these decisions within the DNR-STB process. Below is a flow diagram that depicts the decisions made concerning structural elements

4.3.1.1 Decision-making points in Sketch design

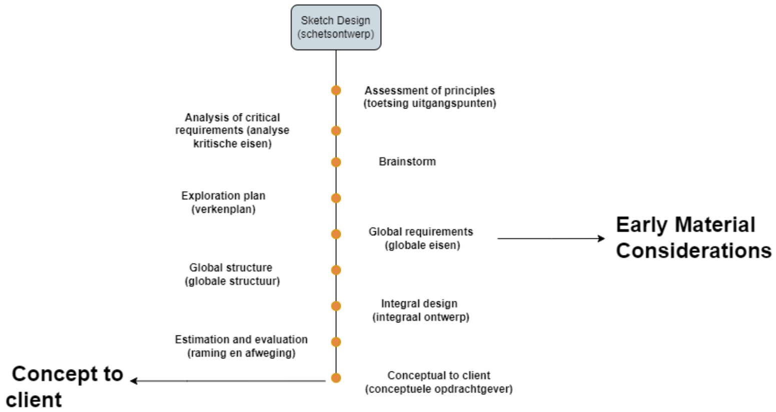

Figure 4.1: Major decision points in sketch design. Source : Anton, Royal HaskoningDHV (2024)

Early Material Considerations

In this early phase, initial ideas and considerations about potential materials are formulated. The structural engineers started exploring different material options that could be suitable for the project. The design team begins gathering and understanding the project requirements, constraints, and any initial ideas or plans the client may already have in mind. This lays the foundation for exploring potential solutions.

Key activities include:

- Identifying the project's key requirements and understanding the client's goals

  At this stage, the engineers examine the project grid, location constraints, boundaries, preferences, and any pre-existing plans or concepts. They also consider how to align these elements with the project goals and client requirements.

  > As quoted by S1: *"Here we look into how to deal with the items we need, it's not decided yet but there's already sort of a plan to reach those."*

  > S2: *"It depends on the assignment from the client."*

  At this stage, the discussions and ideas are still quite vague and exploratory. The team is trying to understand the project's scope and the client's vision before delving into more specific solutions.

  > As indicated by quotes like SC1: *Its very vague"*

- Initial brainstorming of approaches, materials, and strategies

  In this sub-phase of sketch design, the design team starts initial ideation, contemplating potential materials that could be used for the project, though at a very high level. This involves listing possible material options and assessing the feasibility and constraints of using certain materials. However, no definitive material selections are made at this point. The focus is on opening up the discussion and gathering a broad range of ideas and possibilities to explore further as the design process progresses.

During this stage, the team engages in an ideation process, sketching and evaluating multiple design alternatives. This exploration considers the implications of various material choices on the overall design vision and intended user experience.

> S1: *" We think about setting up the structure in this way and we will probably use this or that"*

> SC1: : *" Which materials are we gonna use? And is it possible within this plot? "*

> X1: *" Option exploration, I would say, is happening in this schematic design."*

This stage represents the crucial starting point where the design team aligns with the client's vision, captures project requirements, and initiates the visualization process through open-ended brainstorming and preliminary material considerations. While vague, this lays the groundwork for more focused and detailed design development in the coming phases.

Concept to Client

This stage represents a crucial transition where the initial design concepts and material considerations developed during the sketch design phase are presented to the client for feedback and alignment. This iterative process allows for refining the design based on the client's input, ensuring it resonates with their vision and requirements.

Key activities include:

- Material Considerations

  This sub-phase lays the groundwork for exploring potential materials suitable for the project's needs. While specific selections may not be finalized, the design team will have different options of certain materials that could meet the structural, aesthetic, and performance criteria, as well as new knowledge and lessons regarding the project. As quoted by

  > S1: *" The options are finalized around the end."*

  > S2: *"It depends on the assignment from the client."*

  > X1: *" You will have lessons that you'll work with."*

Client Consultation

A pivotal aspect of the "Concept to Client" stage is actively involving the client in the design process. The design team presents the initial concepts, including material considerations, to the client. This collaborative approach ensures that the client's preferences, aspirations, and feedback are accurately captured and integrated into the subsequent design development phases.

> SC1: *" For sketch design, then you talk to your client, and ask, 'Is this what you think?"*

The "Concept to Client" stage bridges the gap between the designer's creative exploration and the client's vision. Through open communication, presentation of options, and iterative refinement based on client input, this stage lays the foundation for a design that resonates with the client's aesthetic and functional expectations while aligning with the project's technical and sustainability goals, leading to more focused and detailed design development in subsequent phases.

4.3.1.2 Decision-making points in Preliminary design

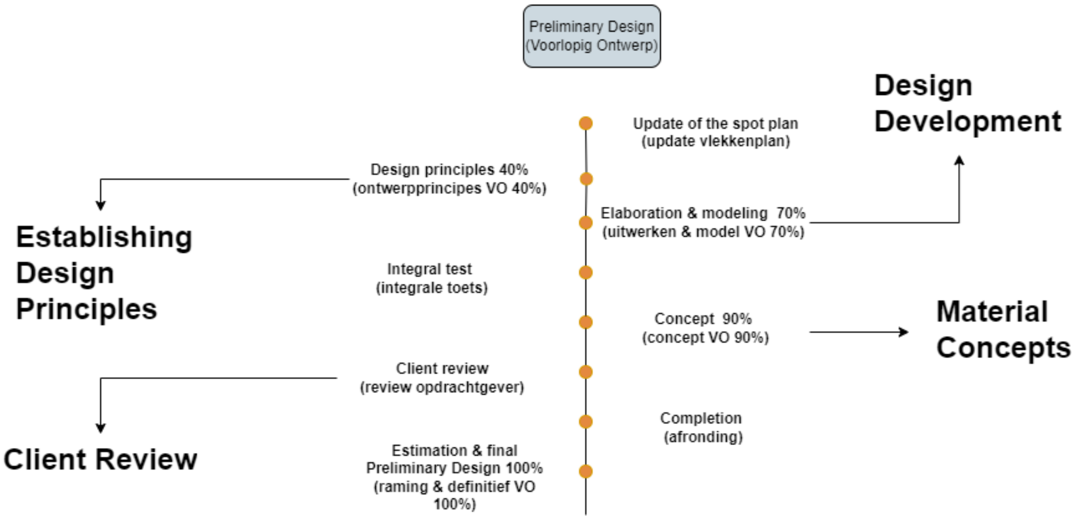

Figure 4.2: Major decision points in preliminary design. Source: Anton, Royal HaskoningDHV (2024)

Establishing Design Principles

The preliminary design marks the stage where major decisions on the overall design approach are made. This involves narrowing down and deciding on one or two preferred design directions to move forward with. At this stage, material choices are almost finalized.

> S2: *" Where decision starts."*

> X1: *"The predesign is kind of development towards, you know, deciding between one or two."*

> S4 *" The material was more or less settled."*

Design Development

The key focus at this stage is the design development process to determine suitable structural systems based on project requirements. This includes investigating the geometry to see which structure or material is best suited based on the requirements defined during the sketch phase. Essentially, the goal is to ascertain which material is the most feasible option.

> SC1:*Look into the span and everything like the height and try to see which structures are suitable based on the requirements, basically what is feasible.*

Material Concepts

By the end of the preliminary design phase, the overall design direction has been firmly established and finalized. Critical choices regarding the overarching design approach and the path forward are determined by this stage.

> X1:*I think predesign stage you already have made a decision on what direction you wanna go to.*

In addition to solidifying the design direction, key decisions related to materials and structural elements are also made. For example, during the preliminary design phase, the team explored material options like timber structures and finalized the initial layout plans, determining the placement of various elements. The final geometry or form of the structural system is decided upon by the end of the preliminary design phase. This is evident from the following quotes:

> S4: *"The final geometry of the structure was decided at the end of the VO phase."*

> S1: *"At the end of the Voorlopig Ontwerp, we handed it in."*

Client Review

During this stage, the design continues to be refined through an iterative process involving client reviews and feedback. Incorporating client input allows for adjustments and alignment with their vision before finalizing the preliminary design.

> SC1: *"We deliver our products through clients, and then the client can say, 'Oh, I want to change this,' or 'I think this would be better. "*

4.3.1.3 Decision-making points in definite design

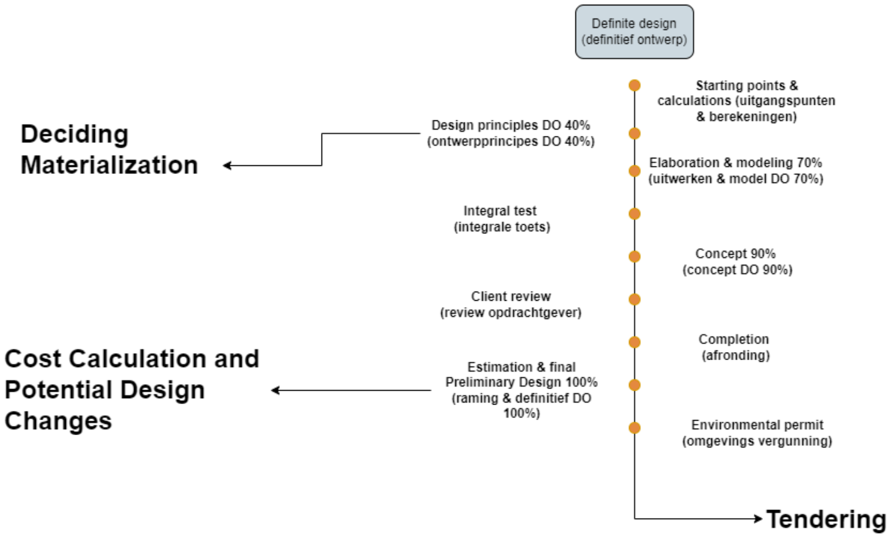

Figure 4.3: Major decision points in the definite design. Source: Anton, Royal HaskoningDHV (2024)

Deciding Materialization

As the project moves into the definite design phase, the focus shifts towards refining the design details and working out the specifics. This is the stage where the design becomes definitive and the team dives deep into detailing. The definite design phase involves making decisions on the precise dimensions, materials, and construction methods for each component of the design. This includes specifying details like:

- The exact spans and sizes of structural elements.
- The specific types of beams and connections to be used.

> SC1: *" In the definite design, we are really working out the dimensions of all the elements."*

> X2: *"We go ahead in detailing."*

> S4: *" How you make the spans, what types of beams you are using."*

Cost Calculation and Potential Design Changes

Toward the end of the definite design phase, a critical step is calculating the detailed cost estimate for the project based on the finalized design. If the cost estimate exceeds the budget, the team may need to consider design changes at this stage to bring the project back within financial constraints. The cost calculation step is therefore an important checkpoint before proceeding to construction. It's the last opportunity to make significant design changes to align the project with the budget.

> S1: *" At the end of the definite design phase, there will be a cost calculation and if it's not within budget, then of course you need to do something about it and then that could also be the moment where they decide to change it towards a cheaper design."*

Tendering

In some cases, the design team prefers to involve the contractor right before the technical design phase. Therefore, the tendering process happens right after the details have been finalized in the definite design phase.

> SC1: *" At the end of the definite design phase, there will be a cost calculation and if it's not within budget, then of course you need to do something about it and then that could also be the moment where they decide to change it towards a cheaper design."*

4.3.1.4 Transition to Common Phases

Having detailed the decision-making points up to the definite design phase for structural elements, it is important to acknowledge that the subsequent phases, namely the definite design plus and technical design, share similarities with both structural and architectural elements. Consequently, the discussion will now shift to address these common phases comprehensively.

Before examining these shared aspects, the decision-making process for architectural elements will be outlined to provide a complete understanding of how both structural and architectural elements are integrated into the final stages of the project. For readers who wish to proceed directly to the common phases, please refer to subsection **4.3.3.**

4.3.2 Material selection for Architectural elements

Material selection for architectural elements is a critical aspect of the building process, as these decisions significantly impact the aesthetic, functional, and environmental attributes of the project. To gain comprehensive insights into how and when these decisions are made, interviews with architects were conducted. These interviews provided valuable perspectives on the timing and context of material selection within the DNR-STB process. The following sections will detail the findings from these interviews, highlighting the decision-making points for architectural elements across the various design phases.

4.3.2.1 Decision-making points in Sketch design

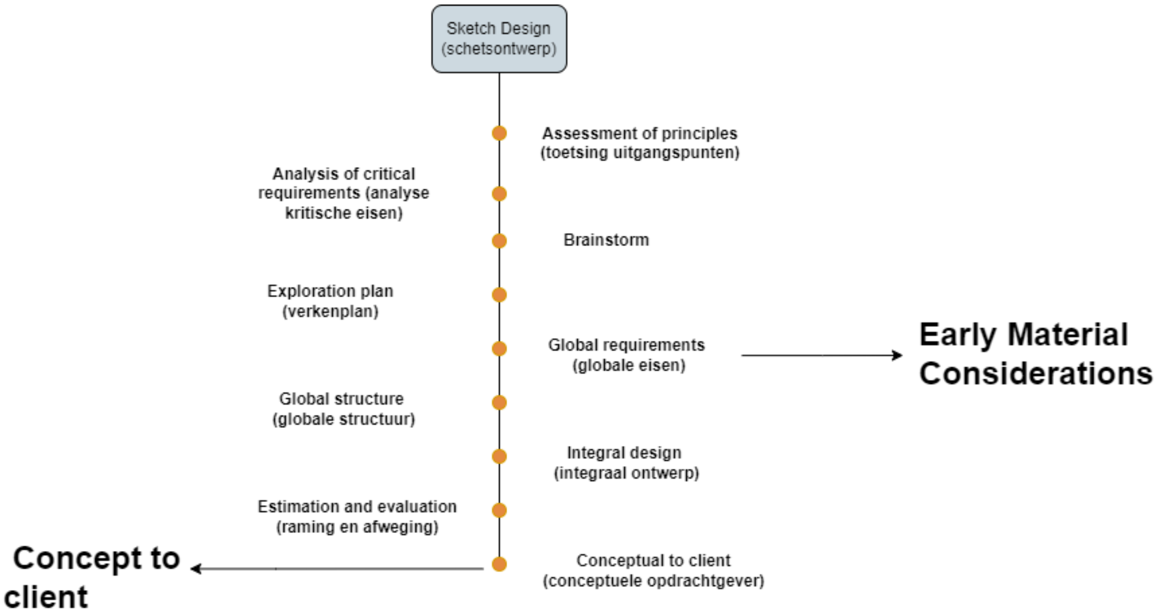

Figure 4.4: Major decision points in sketch design. Source: Anton, Royal HaskoningDHV (2024)

Early Material Considerations

In the sketch design phase, initial decisions regarding the types of materials to be used in the project are made. This stage is considered the starting point where ideas are developed, involving the exploration of various material options and their potential applications within the architectural context. It also involves brainstorming ideas on aesthetics while considering the requirements and ambitions of the client.

Since architectural elements consist of the skin of the building and its aesthetics, the client might have a predetermined idea of what materials they want to represent the skin of the building. For instance, in some projects, the decision to use natural stone finish was established early on.

> A1: *" The aesthetics of the building had a lot of relevance for this client and also for the function of the building. So the material of the facade was selected prior to ensure that it has a certain sort of imaging in the building".*

The early considerations set at this stage are crucial as they set the foundation for subsequent design decisions and align with the project's sustainability goals.

Concept to Client

During the sketch design phase, the design team engages in iterative discussions with the client to refine material choices. This phase is characterized by the alignment of the client's preferences with the project's design vision. These preferences play a significant role in shaping the material selection process. The design team ensures that the selected materials not only meet the client's aesthetic desires but also align with the project's technical and sustainability requirements, setting the stage for more detailed material selection and design development in subsequent phases. The decisions made here, while unrefined, are instrumental in guiding the overall direction of the project.

4.3.2.2 Decision-making points in Preliminary design

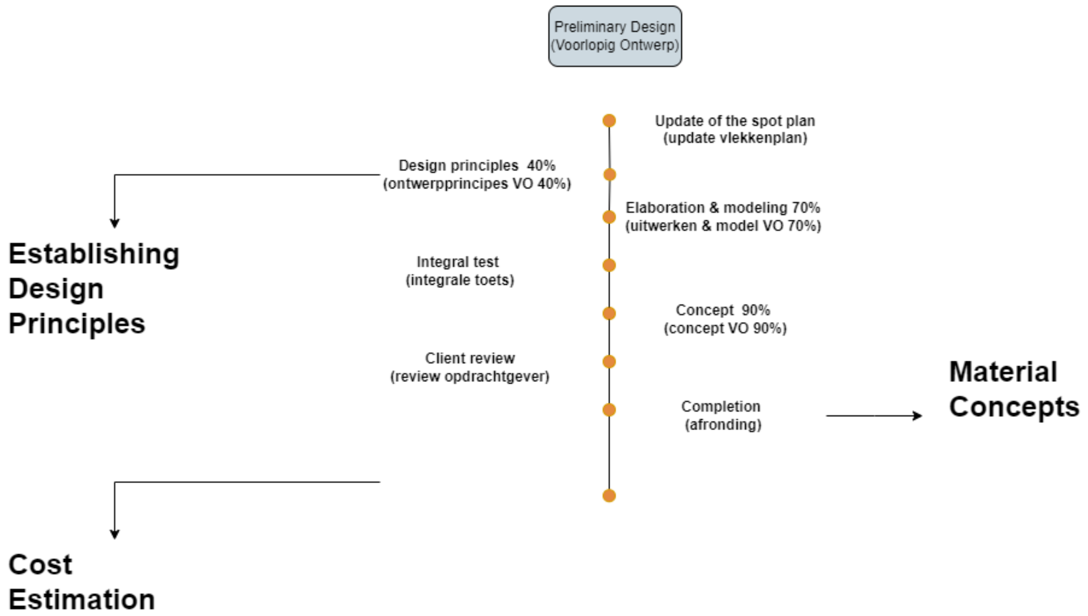

Figure 4.5: Major decision points in preliminary design. Source: Anton, Royal HaskoningDHV (2024)

Establishing Design Direction

During the preliminary design phase, there is an initial understanding of what needs to be done, which further develops in the subsequent design phases. The construction materials and initial ideas for the facade typically start to take shape during this phase. As one interviewee noted:

> A1: *"In the VO (preliminary design), there was some understanding of what needs to be done. Definitely the construction material and maybe the kind of first ideas on, and yeah, probably the facade, would already start there."*.

Therefore there is an indication during the preliminary design about what needs to be done, though the specifics of how it will be executed are not yet fully determined. This phase lays the groundwork for these critical decisions.

Material and Structural Decisions

During the preliminary design phase, the initial material choices from the sketch design are further explored and validated. This phase involves narrowing down options, considering feasibility, and starting to address potential issues like cost and structural requirements. Significant decisions such as making the facade demountable and sustainable are made during this stage.

> A3: *"The thing is, sometimes options are still in the air, but then at least in VO, you researched everything already."*

Cost Estimation

The preliminary design phase is also a critical point for cost estimation and obtaining necessary approvals. Regular cost checks are conducted to ensure the project remains within budget.

> A3: *"We did preliminary design and now we're at the moment to really check the cost and to get approvals."*

This iterative process of cost checking occurs throughout the phases and work on what can be done next to improve in terms of cost, as well as other elements.

4.3.2.3 Decision-making points in Definite design

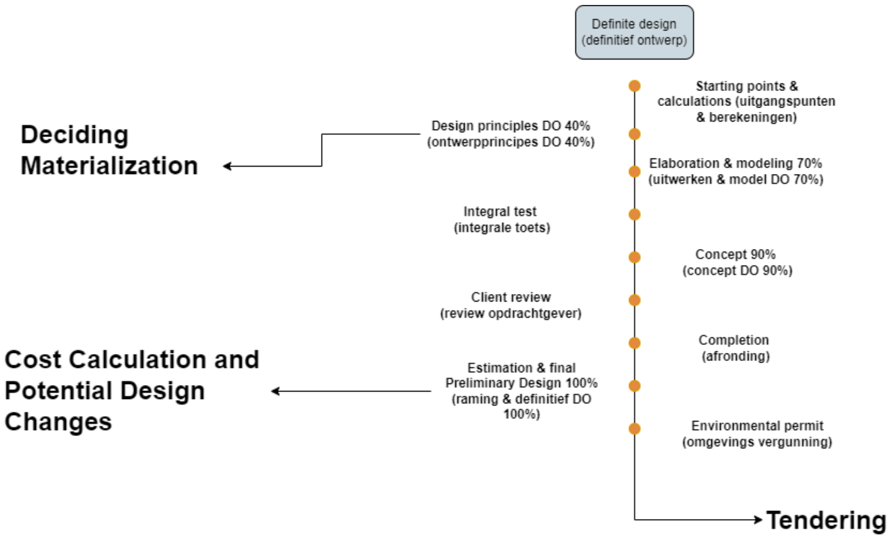

Figure 4.6: Major decision points in the definite design. Source: Anton, Royal HaskoningDHV (2024)

Deciding Materialization

In the definitive design phase, the decisions made in the preliminary design are confirmed and refined. This includes addressing any issues that have arisen and finalizing materials based on detailed cost calculations and other constraints. More detailed material decisions and investigations into specific products, their technical properties, fire ratings, and other critical attributes are carried out.

> A1: *"The idea of what type of insulation will get into the facade was developed in the definitive design."*

Assessments such as LCA (Life Cycle Assessment) calculations and evaluations of embodied carbon are conducted to ensure materials align with sustainability goals. The detailed assessments ensure the materials meet the required sustainability standards. The choice of specific materials, like bio-based insulation and demountable facade systems, is finalized in this phase.

Cost Calculation and Potential Design Changes

Cost calculations are done in this phase to ensure that the project remains within budget. If costs exceed the budget, design changes are made to reduce expenses while still meeting project goals.

> A3: *" There was a sort of a check on the cost calculation."*

Tendering

In some cases, during the definite design phase, the contractor is often brought on board to provide input on constructability and cost. This can occur midway through the phase or after the definitive design is complete.

> A3: *"Sometimes you can have them after the definitive design, so you can do the definitive design yourself and then get the contractor on board. That is also a kind of integrated contract where they do the contract with us."*

4.3.3 Common Sections for Both Structural and Architectural Elements

4.3.3.1 Definite design Plus (DO plus)

Most of the time, when tendering is done before the technical design, it results in more time needed to finalize most things. This results in a DO Plus phase.

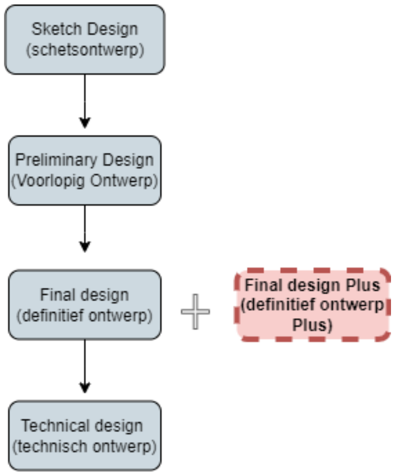

Figure 4.7: definite design Plus

> S1: *"So then we need another couple of months or weeks to finish up DO, and it shouldn't be like that. But still, it happens quite a lot because, at the end of the phase, you didn't have all the information needed."*

This highlights that ideally all client requirements and information should be captured and finalized in the original definite design phase. In practice, it often takes additional time and iterations to reach that phase.

4.3.3.2 Decision-making points in Technical design

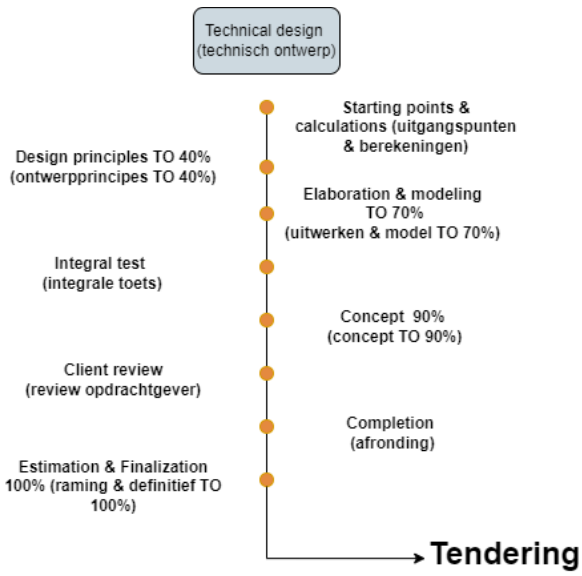

Figure 4.8: Major decision points in technical design. Source:Anton, Royal HaskoningDHV (2024)

The technical design or execution design is the phase where all the design details and selections have been finalized. At this stage, the next step is to proceed with the tendering process.

> SC1: *"The contractor can really start from that."*

4.3.4 Differing Decision Points: Material Selection for Architectural and Structural Elements

In the decision-making process for material selection, there is a notable difference between how architectural and structural elements are handled, particularly after the preliminary design phase. For architectural elements, there remains an opportunity for changes even after the preliminary design phase. Although extensive research and considerations are conducted during this phase, final decisions on materials are often made only in the definite design phase.

> A3: *" The thing is, sometimes options are still in the air, but then at least in VO, you researched everything already."*

In contrast, for structural elements, the material decisions are typically finalized by the end of the preliminary design phase. The direction and final geometry of the structural components are decided much earlier than architectural elements, leaving less room for changes in the definite design phase.

> X1: *" In the predesign stage you already have made a decision on what direction you wanna go to."*

> S4: *" The final geometry of the structure was decided by the end of the VO phase."*

This difference highlights the different approaches for material decision-making in architectural versus structural elements.

4.4 Barriers

This section details the different barriers discovered while conducting interviews with various stakeholders involved in the design process. The barriers mentioned below consist of those that hinder the decision making process for material selection from achieving its desired emission goals.

4.4.1 Late-Stage Design Changes

A significant challenge encountered by design teams is the frequent occurrence of substantial changes to the project scope and materials during the later stages of the design phase. These changes are often driven by various factors, including budget constraints, new information, or shifting priorities.

Infrequent budget checks

Cost or budget is one of the most critical factors influencing material selection in construction projects. The cost of materials directly impacts the overall project budget, and staying within financial constraints is a top priority for most clients and construction teams. This aligns with the findings from the literature review, which emphasizes the significant role of financial stability in material selection decisions. One of the primary reasons for late-stage design modifications is the lack of frequent and thorough budget checks throughout the design process. As mentioned by the interviewees, key pricing checks on material selection are often conducted late, mostly at the definite design (DO).

> S1: *"At the end of the definite design phase, there will be also a cost calculation".*

Structural engineer S3 also confirmed that cost calculations are sometimes performed in the TO phase. These delayed cost assessments can lead to significant changes in both the design and material selection.

Balancing cost with sustainability is an ongoing challenge in the construction industry. When budget checks are not conducted regularly, the true cost implications of the project may only become apparent towards the end of the design phase. This delayed realization can result in a mismatch between the initial sustainability ambitions and the available budget. Consequently, the design team may be forced to make compromises and alterations to the original plans to align with the financial constraints, often favoring cheaper, less sustainable designs. The impact of these late-stage changes can be particularly detrimental to the project's emission reduction goals. Materials and solutions that were carefully selected for their environmental benefits may be replaced with less emission-friendly alternatives in an effort to reduce costs. This not only undermines the project's sustainability targets but also affects the overall environmental performance of the building.

> X1: *"Because when you start considering the cost, they really begin to notice and start making different decisions. In the end, a lot of sustainable materials just get replaced with less sustainable options because of the pricing."*

This statement highlights the common trade-off between sustainability and cost that arises when budget constraints come into play.

Late Changes Due to Inadequate Initial Planning

Inadequate initial planning can significantly affect material decisions in construction projects, often leading to late-stage changes that compromise sustainability targets. These changes are typically driven by insufficient research and poorly defined sustainability criteria during the early stages of the project. Proper planning during the initial design phases is crucial for making informed material choices. When project teams fail to thoroughly explore sustainable material options early on, they tend to default to conventional materials with higher environmental impacts. This oversight results in projects that do not fully capitalize on opportunities to minimize resource consumption, reduce waste, and lower carbon emissions.

Early involvement of sustainability consultants is essential. However, interviews revealed that these experts are often brought in too late to influence initial material decisions significantly. Without their input, project teams may overlook more sustainable alternatives.

> SC1: *"Sometimes there is already a design made, and they are only supporting the decision later on in the process. As a result, they could only support or work towards making the selected material more sustainable."*

Additionally, the absence of clearly defined sustainability targets and material performance criteria from the outset leads to a lack of direction in material selection. Without specific goals related to environmental performance, such as embodied carbon reduction targets or indoor air quality standards, it becomes challenging for project teams to prioritize sustainability effectively. Inadequate initial planning can also lead to discrepancies between the initial design and the actual project requirements as they evolve. Structural Engineer S1 mentioned a project where they initially designed a large part in timber. However, it was later discovered that the design no longer matched the initial architectural plans, necessitating a change from timber to steel. Similarly, PM1 explained that changes made later in the process, such as during the technical design phase, can have substantial impacts, requiring updates to detailed elements of the project and leading to complications that can be complex, costly, and time-consuming (Bassa, Reta, Alyew & Tora, 2019).

> PM1: *"The further you are in the process, the more effect change has. In practice, even at the end, changes can happen that affect the basic starting criteria."*

Stakeholder Influence

A significant challenge in implementing emission-free construction practices arises from the client's role in the decision-making process. Clients play a crucial role, and their understanding and commitment to emission reduction goals can greatly influence project outcomes. Often, clients may initially express enthusiasm for sustainable designs but fail to grasp the full implications and requirements of achieving those objectives. This can lead to a misalignment between the client's expectations and the necessary actions and investments needed to realize a truly emission-free project.

For example, S3 mentioned a project where the client initially requested a top-ranking sustainable building without setting any cost limits. However, as costs became apparent, the client's requirements had to be adjusted:

> S3: *"For example, in the XYZ project, the client started off with a request. OK, I want to make a top-ranking sustainable building and I'm not setting any cost limit at the moment. But in the end, the costs were differentiating anyways, so we had to reset their requirements".*

This can lead to a misalignment between the client's expectations and the necessary actions and investments needed to realize a truly emission free project. It also means losing the opportunity to make material choices that are emission-friendly, as well as losing time.

> S3: *"But yeah, that's sometimes hard and sometimes we have clients that have very high ambitions. But when they hear the price, for example, they also change the design."*

4.4.2 Transparency and Interdisciplinary Collaboration

Transparency and effective collaboration among different disciplines are crucial for the success of sustainable construction projects. The open sharing of information and addressing challenges collaboratively helps in developing an effective project outcome. However, the lack of transparency and communication barriers between various stakeholders often hinder the decision-making process, particularly during the design phase. Research has shown that a lack of transparency leads to improper coordination among the different parties involved and results in ineffective decision-making in construction projects (Brady, 2014). Effective collaboration between major stakeholders involved in the decision-making process, such as architects, structural engineers, contractors, and clients, during the design phase leads to valuable project outcomes. However, as evident from the interviews conducted, the lack of transparency remains a prevalent issue in the construction industry.

One architect stated,

> A2: *"I think it's transparency in the process, which is extremely important, and it is very important in understanding what different disciplines are doing."*

This sentiment was also shared by a sustainability consultant,

> X1: *"The contact within disciplines should be good. That helps the process a lot, and if that's a bit more difficult then it can also affect the progress because if I think of something and my colleague from a different discipline thinks of something else."*

These insights highlight the need for improved transparency, especially during the design phase, where critical decisions are made that impact the project's sustainability outcomes (Klotz, Horman, Riley & Bechtel, 2009). Architectural decisions, such as space layout and building orientation, have significant implications on the structural design, building performance, and the work of various disciplines involved. For instance, the choice of an open floor plan may require a different structural system compared to a compartmentalized layout, affecting the work of structural engineers. Similarly, the orientation of the building and placement of windows impact the building's energy performance, influencing the design of HVAC systems by MEP engineers.

His need for an integral approach is reflected in the comment from one interviewee:

> A1: *"The integral approach is very important for any sustainability ambition to be addressed, because, for instance, one impact of having something will impact the architecture of the space will impact the way they structure is there will impact the performance of the building and will impact multiple all the different disciplines."*

Therefore, it is crucial not to disregard the impact each discipline has on one another.

4.4.3 Balancing Contractor Involvement and Emission Goals

The involvement of contractors in the decision-making process significantly impacts the achievement of emission-free goals in construction projects. According to section 3.4.5, we get a thorough analysis on the perspective of the contractor, where we realise the contractors primarily focus on profit, which can affect material selection processes. The timing and extent of contractor involvement vary depending on two important factors:

1. **The phase of Contractor Involvement in the Design Process**

   The design phase at which the contractor is introduced to the project is crucial, as it determines the level of control the contractor has over design and material selection. There are two primary timings for contractor involvement:

- **Early contractor involvement (ECI)**

  ECI is a collaborative approach that includes the contractor from the early stages of the project. This early involvement leverages the contractor's expertise in material selection, potentially reducing emissions by identifying issues early and developing innovative solutions that balance cost, quality, and environmental performance (Rodrigues & Lindhard, 2023).

  However, ECI can present challenges, particularly when contractors prioritize cost over sustainability. Sustainable materials and practices often come with higher costs, leading contractors to push for changes that may conflict with the project's emission goals (Salam et al., 2019). It also depends on the contractor's experience, as sometimes contractors are more familiar with certain types of materials and may push for designs favoring their preferences:

  > S3: *"The contractor comes into view at certain points. They may or may not have experience with wooden structures, for example, and that can impact decision-making. Often, they have different visions of the design and want to change things".*

  Additionally, as noted during interviews, since sustainable materials and practices often come with higher costs, contractors may push for changes that reduce the sustainability of the project. These findings align with Chegut, Eichholtz and Kok (2019), who found that buildings aiming for BREEAM excellent and outstanding ratings are on average, 40-150% more expensive to design.

  > S5: *"If you invite a contractor at the earlier stage, you will end up with a price with some more margin".*

  Furthermore, in an ECI approach, there may be limited ability to explore other contractor options through a competitive tender process.

- **Traditional Project Delivery**

  Traditional project delivery, also known as Design-Bid-Build (DBB), is the most commonly used approach in a building process, where the design and construction phases are separate. In this method, the client initially contracts the architect and engineer to design the project, and towards the end of the design phase, separately contracts with a contractor to build the project based on the completed design (Serginson, Mokhtar & Kelly, 2013). In traditional projects, the contractor is typically involved only after the design phases are complete, during the construction stage. This late involvement limits the contractor's influence on design decisions, potentially reducing concerns associated with early contractor involvement. However, it also limits opportunities for the contractor to provide valuable input on design decisions that impact constructability and sustainability (Sødal, 2014). This can lead to increased design changes, rework, delays, and additional costs (Khahro, Shaikh, Zainun, Sultan & Khahro, 2023a). The sequential nature of traditional project delivery can foster an adversarial relationship between the architect, contractor, and owner, reducing incentives for collaboration and innovation. Despite these challenges, traditional project delivery remains widely used, especially for projects with clear scope, definition, and limited complexity.

2. **The Level of Requirement in the Contract**

The involvement of the contractor in the design process and issues with late changes in the project often stem from the lack of high-level detailing or setting requirements early in the project. When important parameters such as emission goals, criteria, or detailed requirements are not clearly defined and specified early, several problems can arise. Without a clear framework or targets to guide decision-making, the project team may struggle to make informed decisions that align with the desired project outcomes (Khahro et al., 2023a). This can lead to misinterpretation, potential misalignment, and late changes or additional work later in the project, undermining sustainability objectives.

4.4.4 Skipping of phases

Design stages lay the groundwork for integrating emission friendly practices into construction projects. The DNR-SBT process, detailed across 10 phases from project initiation to handover, is notably intricate and can extend over a lengthy period, making timely completion a challenge. In practice, modifications to this process are not uncommon. For instance, to expedite project completion, it's sometimes necessary to skip certain phases. This approach sees steps like the Schematic Design within the design phases being bypassed. PM1, reflecting on this practice, remarked :

> *" You might not do all the tasks described, and sometimes you want to speed up, especially with simpler projects. You sometimes skip the Schematic Design (SO). One of the main reasons for skipping it is to avoid the time it takes for each phase to be checked and approved. By skipping the SO phase, things tend to move smoother, but of course, the risk is that you might head in the wrong direction. What we often see is that, in the rush, some steps are forgotten or skipped to speed up the process. This is not really clever because it can easily lead to having to do rework later."*

However, while such shortcuts can reduce time, they bear the risk of project misdirection and the potential for increased rework due to overlooked steps. This practice not only underscores the significant challenge of ensuring efficient project outcomes but also introduces risks related to project misalignment, potentially leading to increased rework, and importantly, missed opportunities for incorporating emission friendly practices and materials from the project's early stages.

4.4.5 Lack of Data and Knowledge in the Beginning

A significant barrier to effective material selection in construction projects is the lack of sufficient data and knowledge at the beginning of the design process. The right data and knowledge are vital in every project as they significantly impact the design process and the quality of decision-making.

In the early stages of a project, the availability of knowledge is often limited. This limitation arises because specific criteria, potential barriers, and detailed requirements, which rely on project data, are not yet fully established. For instance, detailed information about material properties, and lifecycle assessment (LCA) data, which provides comprehensive insights into the environmental impact of materials over their entire lifecycle—from production to disposal—is frequently unavailable (Zimmermann et al., 2022). As a result, project teams must rely on assumptions and approximate estimations when creating initial plans. The initial lack of detailed knowledge can lead to suboptimal decisions. Without a clear understanding of all project requirements and potential obstacles, early decisions are often based on incomplete information, leading to errors, increased risks, and missed opportunities. This challenge was highlighted by a material expert who acknowledged a data gap within the early phases of the project, making it difficult to make informed decisions on carbon emissions:

> X1: *"So there's a little bit of a data gap in these early phases in order to really say something about embodied carbon in a conceptual phase. At a very early stage, you don't have a very clear idea of the quantity of materials going in and thereby you cannot say a lot about what its carbon impact will be"* .

The effect of being equipped with the right knowledge significantly impacts the design process as a whole. Bragança et al. (2014) developed a graph illustrating the potential impact of early decision-making on the design process and the effect of cost. This is supported by the research from Hester et al. (2018), which shows that the level of data in a project gradually increases as you move from the earlier phases to the end. This demonstrates that in the early stages of a project, the limited amount of available knowledge can significantly impact the quality of decision-making towards emission-free goals. Jensen, Ahmed-Kristensen et al. (2010) also supported this, highlighting that a lack of information during the decision-making process can lead to fragmented decisions.

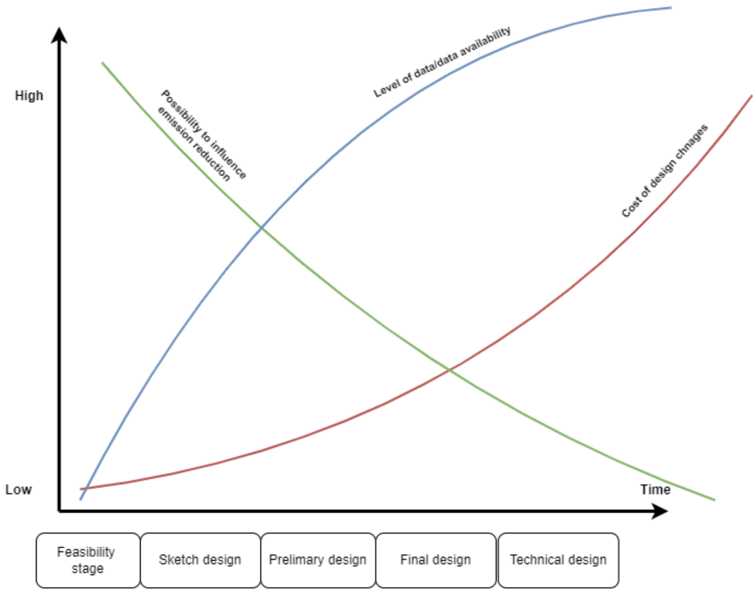

Figure 4.9: Impact of data availability on early-stage decision making, incorporated from Bragança et al. (2014); Hester et al. (2018)

Similarly, insufficient research into sustainable material options early on can lead to the selection of conventional materials with higher environmental impacts, undermining the project's emission goals. The absence of well-defined emission targets and material performance criteria at the project's beginning can further complicate decision-making. As the design progresses and more information becomes available, the team may realize that certain decisions or materials do not align with the project goals. This can result in rework, delays, and increased costs as the project tries to course-correct and incorporate such considerations later on.

4.4.6 MPG and MEP Systems

The Mechanical, Electrical, and Plumbing (MEP) systems are an integral part of a building's infrastructure, essential for operational functionality and occupant comfort. However, they also contribute significantly to a building's overall energy consumption and carbon emissions. The Dutch government's MPG (Milieuprestatie Gebouwen) regulation sets limits on the allowable carbon emissions for buildings, which vary for different building types. Based on findings from the interviews conducted as part of this research, several shortcomings in both MPG and MEP systems have been identified, hindering their effectiveness in promoting sustainable and low-carbon construction practices.

MEP Systems

MEP systems are critical for the operational functionality and comfort of buildings, but they also contribute significantly to a building's overall energy consumption and carbon emissions. Research shows that HVAC systems alone can account for 15-36% of the total embodied carbon in office buildings (Kiamili, Hollberg & Habert, 2020). This substantial footprint underscores the importance of integrating sustainable practices within MEP design. A primary barrier is that MEP material choices are predominantly driven by functional requirements rather than environmental impacts. As one interviewee noted,

> ME1:*" Material choices are mainly based on functional aspects."*

This prioritization results in the continued use of traditional materials such as steel for ventilation ducts and air handling units, and copper for cabling and piping, despite their significant carbon footprints. The environmental impact of these materials is often not the primary consideration during the design phase. The availability of sustainable alternatives for MEP materials is severely restricted. Current market offerings do not provide viable options for many applications within large buildings. As mentioned in the interview,

> ME1:*" For large buildings, we basically only have one choice: steel."*

This limitation makes it challenging to reduce the carbon footprint of MEP systems effectively

The MPG regulation

1. While the MPG regulation provides a comprehensive framework for accounting for emissions, issues often arise from the implementation at the project level. When using materials such as wood structures, additional systems like Mechanical, Electrical, and Plumbing (MEP) systems are required to comply with fire safety and other regulations. For instance, although timber is chosen for its lower structural emissions, it often necessitates more extensive MEP systems. One interviewee highlighted this issue, stating:

   > ME1: *"Wood is good in terms of emissions but then you will be using more materials in MEP systems."*

   This also includes fireproof coatings like gypsum, which have their own embodied carbon, leading to an incomplete assessment of a building's total emissions. Although the materials in MEP systems can be estimated and most are included in the MPG database, the problem often lies with projects not performing proper MPG calculations. As mentioned by the materials expert

   > X1: *"The MPG tools do include the data. It's the approach that you take to make the assessments. It's not a problem of MPG; it's more the problem of the people who are calculating the impact."*

2. Secondly, the consideration of end-of-life feasibility for building materials is crucial in assessing the overall sustainability and environmental impact of construction practices. During the interviews, it was highlighted that the current MPG framework does not adequately account for the potential reusability of certain biobased materials, such as wood. This was discussed in detail in the interviews

> ME1:*"If you look at wood or you look at biobased materials for insulation, the way it (MPG) calculates the impact is very disadvantageous for natural materials because it assumes that at the end of the buildings life you burn it and CO2 gets released. Whereas if you have concrete, you can reuse it".*

This approach leads to a biased assessment that favors traditional materials like concrete and steel over potentially more sustainable options and fails to recognize the long-term benefits and reusability of materials such as wood. The current method of assuming biobased materials are burned at the end of their lifecycle overlooks the potential for these materials to be reused or repurposed, thereby contributing to a more sustainable construction practice. Additionally, it is important to note that biobased materials like wood can face challenges related to their end-of-life management. Wood, for example, can lose strength and integrity after processes such as compression, which can complicate its reusability. Research indicates that compression can significantly affect the mechanical properties of wood, making it less suitable for structural applications upon reuse (Zhao, 2017). These factors must be considered to provide a fair and comprehensive assessment within the MPG framework.

Chapter 5

Summary of Barriers

Before moving into the proposed solutions, it is essential to understand the primary barriers that hinder effective material selection towards emission reduction in construction projects. The following table summarizes these barriers, providing a foundation for the subsequent solutions.

Barrier	Concern	Why is it a concern?	What is the issue?	Source
Lack of Early Decision Making	Delayed critical decisions in project phases	Early decisions facilitate cost-effective choices and allow for optimization and innovation. Delayed decisions reduce opportunities for these benefits and make implementation costlier.	Decisions taken late become difficult and expensive to implement, reducing optimization and innovation opportunities.	Literature

Barrier	Concern	Why is it a concern?	What is the issue?	Source
Lack of Knowledge, Expertise, and Reliable Information	Gap in knowledge and expertise regarding emission-friendly materials	Decision-making heavily relies on accurate data and understanding of emission-friendly products. Lack of this knowledge leads to poor material decisions that do not meet project requirements.	Preference for familiar materials over better alternatives, incomplete or inaccurate information leading to poor choices, lack of tools and abilities for informed decisions.	Literature
Inadequate Early Project-Specific Information	Limited reliable data regarding project requirements and ambitions during initial phases	Inadequate information at early stages complicates material selection and other crucial decisions. This affects the ability to make impactful decisions and estimate construction costs accurately.	Lack of comprehensive data on feasible requirements, site-specific factors, and material performance in specific contexts, leading to inefficient and less productive outcomes.	Literature
Stakeholder Conflicts	Problems arising from multiple disciplines involved in decision-making	The decision-making process for material selection involves various stakeholders with differing priorities, making consensus difficult without proper collaboration.	Lack of coordination and cooperation among stakeholders leads to disagreements, delays, and missed opportunities for selecting suitable materials.	Literature
Late-Stage Design Changes	Significant changes to project scope and materials during later design phases	Late-stage changes driven by budget constraints, new information, or shifting priorities can lead to compromises that affect sustainability and project performance.	Delayed cost assessments and inadequate initial planning lead to the replacement of sustainable materials with cheaper, less sustainable options, undermining emission reduction goals.	Interview

Barrier	Concern	Why is it a concern?	What is the issue?	Source
Transparency and Interdisciplinary Collaboration	Lack of transparency and communication barriers between various stakeholders	Lack of transparency leads to improper coordination among different parties, hindering effective decision-making and impacting the project's sustainability outcomes.	Ineffective collaboration between stakeholders as well as not addressing material selection during interdisciplinary meetings results in suboptimal project outcomes, affecting architectural, structural, and MEP systems.	Interview
Balancing Contractor Involvement and Emission Goals	Contractors primarily focus on profit, affecting material selection processes and emission goals	Contractors' focus on cost over sustainability can lead to choices that conflict with emission goals. The timing and extent of contractor involvement significantly impact the control over design and material selection.	Early contractor involvement (ECI) can lead to cost-driven decisions that compromise sustainability. Traditional project delivery limits contractors' input on sustainable design choices, leading to rework and delays.	Interview
Lack of Data/Knowledge	Insufficient data and knowledge at the beginning of the design process	Limited availability of specific criteria, material properties, and lifecycle assessment (LCA) data can lead to suboptimal decisions, errors, increased risks, and missed opportunities.	Early decisions based on incomplete information can lead to errors, increased risks, and the selection of conventional materials with higher environmental impacts, requiring rework and causing delays.	Interview

Barrier	Concern	Why is it a concern?	What is the issue?	Source
MPG and MEP Systems	Shortcomings in MPG regulation and the environmental impact of MEP systems	MEP systems contribute significantly to a building's energy consumption and carbon emissions. MPG regulation often leads to an incomplete assessment of a building's total emissions and fails to account for the reusability of biobased materials.	MEP material choices prioritize functionality over environmental impact, and limited sustainable alternatives are available. The MPG framework disadvantages biobased materials by assuming they are burned at the end of their lifecycle, favoring traditional materials like concrete and steel.	Interview

Chapter 6

Recommendations

6.1 Early Decision-Making with Knowledge Gap Reduction

To address the issues arising from a lack of project knowledge and the delay in making material selection decisions, a two-stage solution is proposed.

6.1.1 Stage 1: Establishing Emission Objectives Early

The primary goal of this stage is to establish emission objectives early in the project. As per the provided data, targeting emission goals early in the project yields the most benefits. Therefore, one of the key strategies to address these challenges is to focus on the feasibility stage, which occurs before the sketch design phase.

The Importance of the Feasibility Stage

The feasibility stage is a critical phase in the project lifecycle where the viability of the project is assessed, and key decisions are made regarding the project's scope, objectives, and constraints (Shen, Tam, Tam & Ji, 2010). This stage provides an opportunity to engage with the stakeholders early on and ensure that they have a realistic understanding of the implications and requirements of building an emission-free building. By getting involved in the feasibility stage, the project team can define their sustainability goals, assess the practicality of their ambitions, and set realistic targets within their budget constraints. This early collaboration helps align expectations, reduces the likelihood of late-stage changes, and ensures that the project's sustainability objectives are well-understood and agreed upon by all stakeholders.

Involving Sustainability Experts in the Feasibility Stage

Sustainability experts such as sustainability consultants and material experts are crucial for achieving emission goals in a project. Their early involvement is recommended as they possess vital information, knowledge, and experience essential to the project. This is supported by the following interview statements:

> S1: *"So I think it's helpful if you have more knowledge about it or have experts on certain materials."*

> S2: *"I think it's helpful to seek assistance from colleagues who have more knowledge or are experts in certain materials. I would definitely contact these specialized colleagues for their expertise."*

It is crucial to involve sustainability experts or consultants in the process to facilitate effective engagement and goal setting during the feasibility stage. These experts can help make informed decisions about emission goals. One of the primary challenges in promoting sustainable construction is conveying its value to clients who are not well-versed or knowledgeable in setting emission goals. With the help of experts, clients can overcome this knowledge gap.

Clients may be primarily focused on short-term costs, so it is important to highlight the long-term financial, environmental, and social benefits of sustainable building practices. By presenting a compelling financial argument, clients can be persuaded to invest in emission-friendly solutions that deliver both environmental and economic benefits over the building's lifecycle. Experts can also assist in translating the client's ambitions into achievable targets and guide setting realistic carbon emission budgets, considering the client's financial constraints and the project's unique characteristics.

However, similar types of projects tend to face the same categories of uncertainty; this suggests that the use of appropriate historical data will enable the desired understanding of the cost implications for the project, even within early stage estimating. Unfortunately, this does not completely solve the issue as risk and uncertainties may be inadequately represented because early cost estimates are susceptible to powerful stakeholder's desires and demands (HM Treasury, 2015).

Critical Considerations for Emission Reduction

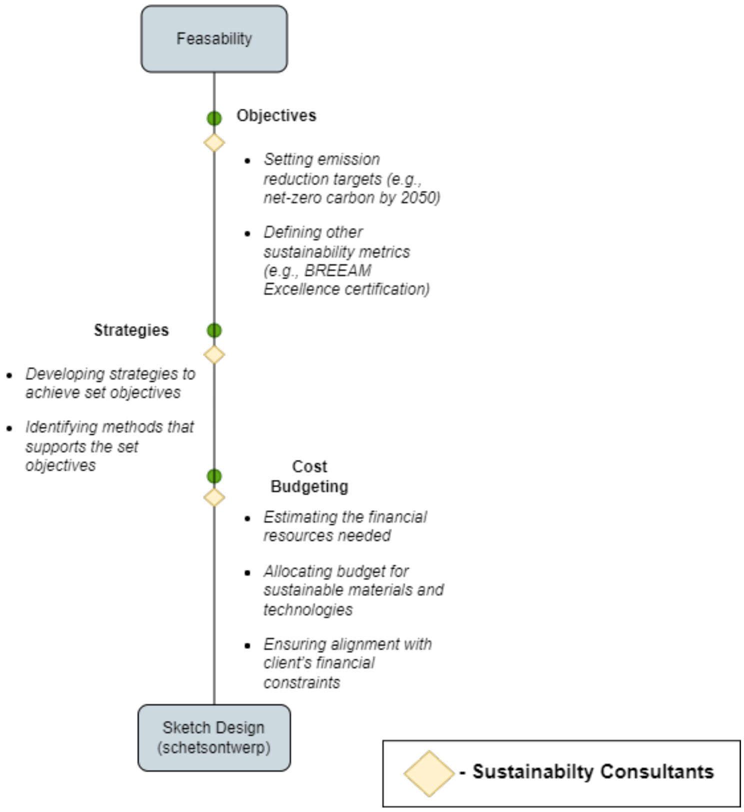

Figure 6.1: Detailing of the feasibility phase

1. Defining Objectives: At this stage, it is crucial to clearly define the specific sustainability goals and targets for the project. This includes setting measurable objectives for emission reduction, such as achieving net-zero carbon emissions or aligning with science-based targets. Here the sustainability consultants help translate the client's ambitions into realistic and practical objectives, ensuring that goals are measurable and achievable within the project's context. Additionally, energy efficiency goals should be established, outlining targets for reducing energy consumption through design strategies and the incorporation of energy-efficient systems and technologies. Furthermore, the team can explore the potential for achieving sustainability certifications like BREEAM Excellence or LEED Platinum, which provide comprehensive frameworks for assessing and benchmarking the project's environmental performance.

2. Developing Strategies to Achieve Goals: Once the sustainability objectives are defined, the next step is to develop strategies to achieve these goals. This involves identifying and evaluating various sustainable construction methods, materials, and technologies that can be implemented throughout the project lifecycle. These strategies should be carefully aligned with the client's goals, budget constraints, and the project's unique requirements. These strategies should be carefully aligned with the client's goals and the project's unique requirements. Sustainability consultants are integral to this phase as they evaluate and recommend sustainable construction methods, materials, and technologies. Additionally, the project manager can be involved to ensure that the strategies are feasible and effective.

3. Cost Budgeting: Implementing sustainable practices often requires additional upfront investments, making cost budgeting a critical aspect of the feasibility phase. The team should estimate the financial resources needed to implement the proposed sustainability strategies, allocating appropriate budgets for sustainable materials, technologies, and processes. In this phase, the cost engineer provides detailed cost estimates and budgeting for sustainable strategies, while the sustainability consultant assists in understanding the cost implications of various sustainability measures and technologies. The client is also involved in discussions to ensure that the budget aligns with their financial constraints and goals.

By having these discussions early on, the project team can help clients set realistic goals that align with their budget and the project's constraints. This approach also minimizes the risk of scope creep (Ajmal, Khan, Gunasekaran & Helo, 2022), budget overruns, and late-stage design changes that can compromise the project's emission performance.

Feasibility Report

The outcome of the feasibility stage would be a feasibility report that outlines the project's viability, objectives, and constraints. To ensure that emission reduction remains a central focus throughout the project lifecycle, it is crucial to integrate the agreed-upon emission goals and targets into the feasibility report. The feasibility report should include a dedicated section outlining the client's emission objectives, the proposed strategies for achieving those objectives, and the estimated costs and benefits associated with each strategy. This documentation serves as a reference point for all stakeholders throughout the project.

Margin of error in stage 1

In the early stages of construction projects, cost estimation is often subject to significant uncertainties due to incomplete design details and limited project information. This can lead to a higher margin of error during its estimation. A study by Asal (2014) found that the percentage error in cost estimates can vary significantly, ranging from -23.6% to +22.8%, indicating a high level of uncertainty in early-stage estimates. Asal (2014) research highlights that factors such as the level of project definition, the availability of detailed design information, and the experience of the estimating team play crucial roles in determining the accuracy of these early estimates. To address the challenges of early-stage cost estimation, researchers have explored the use of Artificial Neural Networks (ANNs). Matel, Vahdatikhaki, Hosseinyalamdary, Evers and Voordijk (2022) in their study demonstrate that ANNs can obtain fairly accurate cost estimates, even with small datasets. Their model showed a 14.5% improvement in accuracy compared to other similar works.

In summary, the error margin in early-stage cost estimates can range from approximately 10% to 20%, depending on the completeness of design details, the experience of the estimator, and various project-specific factors. This variability underscores the importance of continuously refining estimates as more project information becomes available. As mentioned in the above sections in the early stages of construction projects, cost estimation is often subject to significant uncertainties due to incomplete design details and limited project information. This leads to a higher margin of error during its estimation.

6.1.2 Stage 2: Addressing the Knowledge Gap

In Stage 2 of the solution, the main issues being addressed are:

1. Reducing the margin of error
2. Establishing definitive criteria for emission plans

Reducing the margin of error

Graph Analysis

As mentioned in Stage 1, due to the lack of proper data and sufficient knowledge regarding the project, there is an apparent lack of information in the initial phases of the project. This stage aims to mitigate that issue by reducing the margin of error seen within the first stage. In order to minimize the error margin, a detailed analysis of the graph developed by Bragança et al. (2014); Hester et al. (2018) is required.

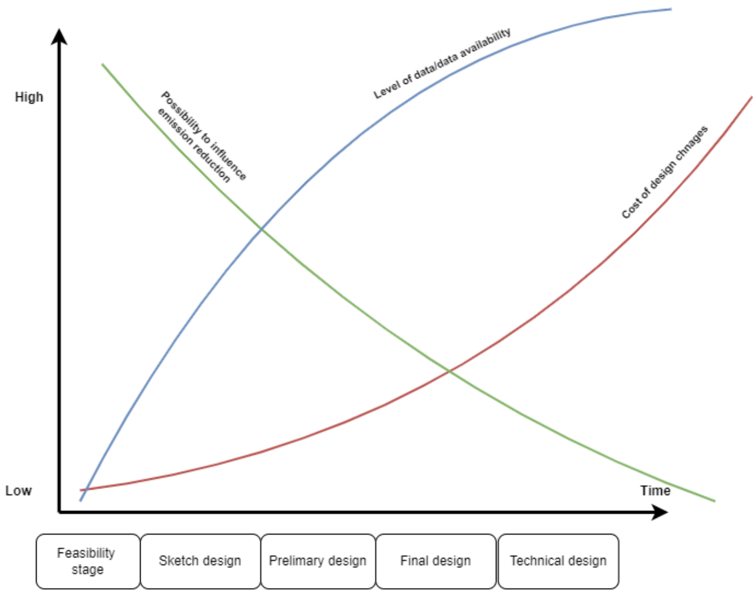

Figure 6.2: The possibility of influencing change, cost, and the level of data available. Incorporated from Bragança et al. (2014); Hester et al. (2018)

The graph depicts three lines that show:

- Possibility to Influence Emission Reduction: This line shows the influence one has on reducing emissions throughout the stages. As supported by numerous reports, the highest influence on emission reduction is at the start of the project, gradually decreasing as the project progresses from feasibility to technical design, with the lowest influence at the technical design stage.
- Cost of Design Changes: This line depicts the changes in cost that can occur throughout the project. This line moves inversely compared to the above one. Here, the cost due to design changes is lowest at the beginning of the project, as there is enough space and opportunity for design changes without affecting key parts of the project. This changes as the project progresses and certain concrete decisions regarding the design have been taken. At this point, changes in design or decisions regarding the project will have a greater impact, and the cost incurred will be high and increasing until the technical design stage.
- Level of Data: This line depicts the level of data available during the project duration. As similar to the literature, it is shown that the level of credible data is the lowest at the beginning of the project. During this phase, the project is still setting its requirements and hasn't progressed

enough to gather useful data. However, as the project progresses, more insights into the workings and details of the project are gained. This is also shown in the graph line as the availability of data increases throughout the different design phases.

In summary, the graph plots an important aspect of every project, showing the critical areas where you can take control or influence the project the most. This section is depicted below.

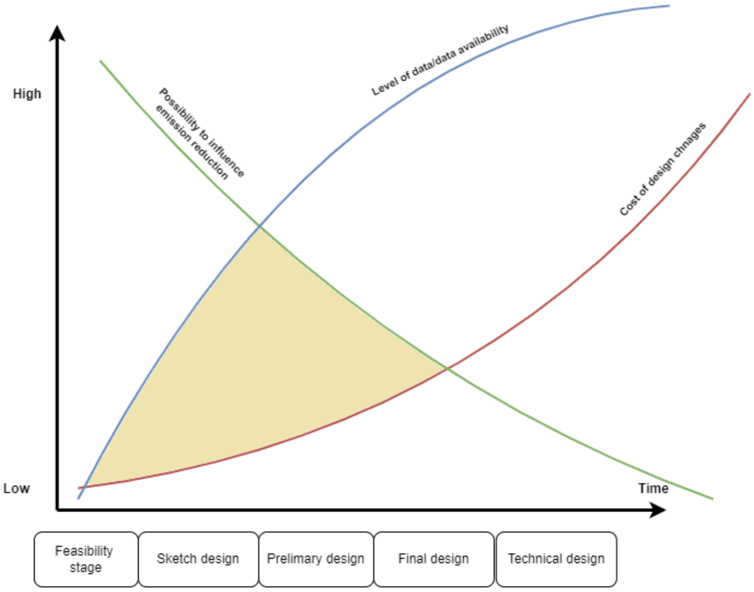

Figure 6.3: Critical area of influence

Identifying the Sweet Spot

To reduce the margin of error, the next step would be to find the sweet spot within the graph, where there is sufficient data available from the project, there is still a possibility to influence emission reduction, and the cost of changes is manageable as designs are still not set in concrete and room for changes is still open without negatively affecting the project. Through the interviews conducted to understand the current decision-making process for material selection, information regarding the level of data available and the amount of changes made at each phase was also derived.

<u>Point at which there is enough data</u>

The analysis of the interviews showed that at the feasibility and sketch design stages, the project had just been initiated, and the amount of data available was sparse, with the project still gaining information. When the project moves on to the preliminary design stage, actual decisions regarding materials start taking form, and feasibility studies on different materials are conducted. Here, the design teams decide on the specific direction they want to move in. Toward the end of the preliminary design, the design team would have conducted extensive research on materials and their properties. A specific point within the preliminary design would be during the phase between "Design principles VO 40%" and "Concept VO 90%". This is highlighted by the following quote:

> SC1: *"I would consider it under design principles and elaboration. I think those are the two. phases where you're really investigating those things."*

This period between 40% and 90% completion in the preliminary design stage is critical, as it involves extensive investigations, evaluations, and decision-making that shape the definite design outcome. This phase lays the groundwork for the subsequent detailed design and documentation stages. This depicts an accurate point within the design phases where you have a high level of detailed information.

Point where there is a positive influence on emission and on the cost of design changes

In construction projects, the ability to influence emission reduction and manage the cost of design changes is a critical aspect. During the early stages of a project, such as the feasibility and preliminary design phases, there is a high potential to influence emission reduction. Decisions made at this stage can significantly impact the project's overall carbon footprint. According to the literature and interviews, the highest influence on emission reduction occurs at the start of the project and gradually decreases as the project progresses from feasibility to technical design. At the same time, the cost of implementing design changes is relatively low during these early stages. This is because the project is still in its conceptual phase, and modifications can be made without significant disruption or additional costs.

The Sweet Spot

The key to effective decision-making is identifying the "sweet spot" where there is sufficient data available, the potential to influence emission reduction is still significant, and the cost of design changes remains manageable. These three factors coincide during the preliminary design phase, particularly between the "Design principles at 40%" and "Concept at 90%" stages. During this period, extensive investigations and evaluations take place, shaping the final outcome while avoiding concrete decisions that strongly shape the design. Therefore, the sweet spot will look as shown below.

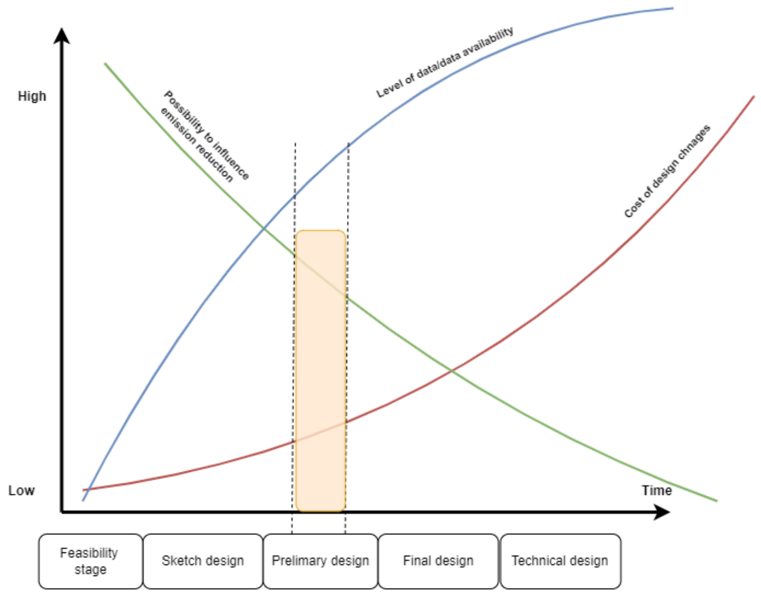

Figure 6.4: Decision sweet spot

Establishing Final Requirements

Based on the above section and graph, it is evident where the most influential decisions backed by data can be taken. Therefore, at this point, the feasibility report will be revised once again. This revision will use newly developed data to set more accurate criteria, following the same method:

- Defining Objectives: Clearly outline the specific sustainability goals and targets for the project.
- Developing Strategies to Achieve Goals: Identify and evaluate various sustainable construction methods, materials, and technologies.
- Cost Budgeting: Estimate the financial resources needed to implement the proposed sustainability strategies.

Here, we refine and reclarify the criteria one last time. This time, they are set in stone, and minimal or no changes are allowed from here onwards, thereby reducing the opportunity for scope creep and ensuring that the project stays on track with its emission reduction goals.

Margin of Error

As the project progresses, more detailed information becomes available, and the accuracy of cost estimates improves. This phenomenon is well-documented in the literature. Hatamleh, Hiyassat, Sweis and Sweis (2018) in his paper emphasizes that the accuracy of cost estimates improves as more detailed and comprehensive information becomes available. The study identifies several critical factors affecting cost estimate accuracy, including clear and detailed drawings, pricing experience, and project complexity. As these factors are better defined and understood, the margin of error in cost estimates decreases.

Initially, during the feasibility stage, cost estimates are based on rough assumptions and high-level data, resulting in a higher margin of error. During this stage, cost estimates can have a margin of error as high as 20% or more. This is because the data used at this stage is often based on preliminary assessments and broad assumptions. As the project moves into the preliminary design stage, more comprehensive data collection and analysis allow for more precise assessments and decisions. At this stage, the margin of error can be reduced to around 5-10% (Ballesteros-Pérez et al., 2020).

This reduction is due to the availability of more detailed and specific data, which enables the use of a Definitive estimate with an accuracy range of -5% to +10%. The increased availability of specific project data during the preliminary design stage allows for more accurate decision-making, significantly reducing the margin of error.

6.1.3 Continuous Monitoring and Feedback

Ensuring that all stakeholders remain engaged and aligned with the sustainability goals throughout the project lifecycle is essential. This involves establishing a structured process for continuous monitoring and feedback. This helps maintain focus on the sustainability objectives and allows for timely adjustments based on ongoing project developments. This reduces the risk of deviations from the sustainability goals.

6.2 Contractor involvement during the design phases

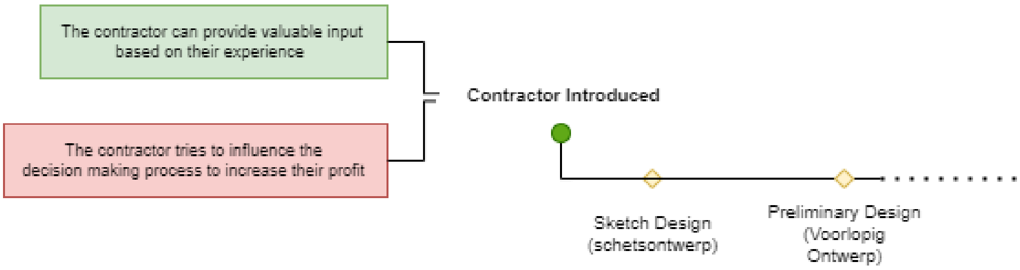

Figure 6.5: Contractor involvement during ECI

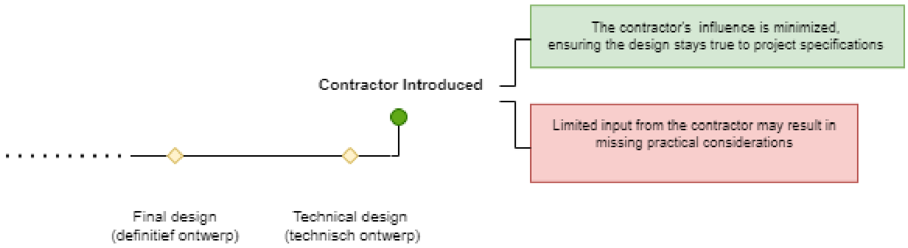

Figure 6.6: Contractor involvement during TPD

The above two figures depict contractor involvement during different types of project delivery methods.

To tackle the above-highlighted issues, we have to rely on the graph developed earlier. As per the interviews conducted, it was evident that the only way to limit the influence of the contractor is by setting concrete criteria in the contract regarding the project's goals and ambitions. However, in ECI cases, the design team lacks a sufficient amount of data in the beginning to set these criteria. Engaging contractors too early, during the sketch design phase, often means there is insufficient data to set specific sustainability clauses in the contract. Early contractor involvement can lead to the prioritization of cost over sustainability, as contractors may push for cheaper, less sustainable materials to enhance profit margins. Similarly, in TPD projects, too much time and too many changes have been made for the contractor to be able to provide any viable advice.

6.2.1 Ideal Phase for Contractor Introduction

From the earlier analysis, the research identified a critical "sweet spot" in the project lifecycle. This sweet spot occurs between the "Design principles at 40%" and "Concept at 90%" stages. By this stage, the project team has gathered comprehensive data on emission goals, material performance, and cost implications. This enables the formulation of precise and enforceable requirements that can be included in the contract.

The decision-making sweet spot, as identified in the analysis, ensures that all necessary information is available to set precise emission requirements. By involving contractors post-sweet spot, the project team can ensure that he goals are firmly established and clearly communicated. Therefore, an apt solution is to create a contract during the sweet spot as per the developed graph, ensuring that all the ambitions of the project based on the feasibility report are translated into the contract. At this stage, the project team can set clear, detailed sustainability clauses and performance criteria in the contract, ensuring that all parties are aligned with the project's emission goals. This timing ensures that the contractor is fully aware of the sustainability goals and bound by the contractual obligations to meet these targets. Setting the requirements at this stage gives the contractor enough opportunity to provide inputs and work together with the design team while making decisions that adhere to the set contract. This approach helps address the primary challenge of insufficient data in the early stages and ensures that contractors are brought into the process when they can contribute effectively without compromising the project's emission goals.

6.3 Enhancing Transparency and Interdisciplinary Collaboration in the Design Process

Several studies have highlighted the benefits of transparency in construction management. Barthel and Seidl (2017) point out that complex problems in the modern era require solutions that may not be achievable by working alone. There is evidence that interdisciplinary collaboration is associated with greater prestige, publication success, and research impact. Increasing process transparency by making information more readily available to all participants helps them foresee and resolve problems in a timely manner (Brady, Tzortzopoulos, Rooke, Formoso & Tezel, 2018). Effective collaboration between architects, structural engineers, contractors, and clients in the design phase results in buildable, high-performance, and desirable project outcomes (Salam et al., 2019).

One effective solution to address the lack of transparency and communication among the various stakeholders involved in the design process, such as architects, structural engineers, MEP engineers, and building physics specialists, is to introduce structured interdisciplinary meetings at regular intervals throughout the design phases.

To foster better collaboration and transparency, it is recommended to establish a series of structured interdisciplinary meetings that take place at key points within and between the main design phases, such as sketch design, preliminary design, definite design, and technical design. These meetings would serve as dedicated periods for the various technical disciplines to come together, share information, discuss design decisions, and ensure alignment across the project. The frequency and timing of these meetings can be tailored to the specific needs of the project, but a suggested approach could be:

1. Kick-off Meeting: Conduct an interdisciplinary kick-off meeting at the beginning of the sketch design phase to establish project goals, emission targets, and communication protocols.
2. Mid-Phase Meetings: Hold interdisciplinary meetings at the midpoint of each main design phase (sketch, preliminary, final, and technical) to review progress, discuss any design changes or challenges, and ensure coordination among disciplines.
3. Phase Transition Meetings: Organize interdisciplinary meetings at the end of each main design phase to review and validate the design outputs, discuss any outstanding issues, and plan for the next phase.
4. Ad-hoc Meetings: Allow for additional interdisciplinary meetings to be scheduled as needed to address specific issues or challenges that arise during the design process.

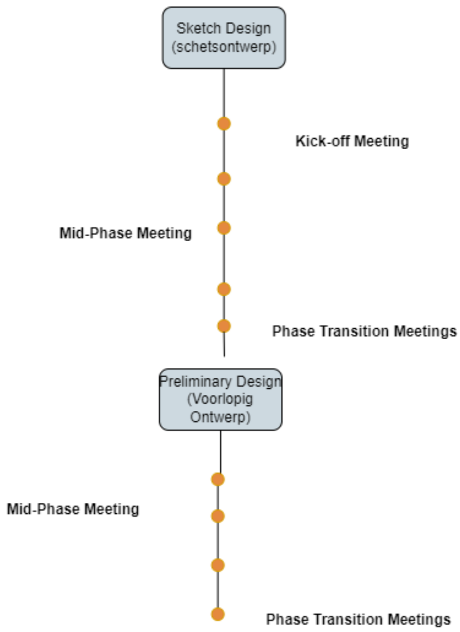

Figure 6.7: Meeting suggestions for stakeholders

Meeting Structure

The meeting should cover key topics such as:

1. Review of project goals and targets
2. Progress updates from each discipline
3. Discussion of design decisions and their impact on other disciplines
4. Identification of potential conflicts or challenges
5. Brainstorming and problem-solving sessions
6. Action items and next steps

During these interdisciplinary meetings, it is vital to foster an environment that encourages open communication, active listening, and collaborative problem-solving. By implementing these structured interdisciplinary meetings throughout the design process, the project team can significantly improve transparency, communication, and collaboration among the various technical disciplines.

6.4 Implementing Frequent Budget Checks Throughout Design Phases

One of the key reasons for material decisions being changed later in the project is due to exceedance observed in the budget during the late design phases, leading the team to shift to cheaper and less emission-friendly materials. To address the issue of inadequate budget management in construction projects, it is essential to implement frequent budget checks throughout the design phases. By regularly monitoring and reviewing the project budget at various stages of the design process, the project team can proactively identify potential cost overruns and take corrective actions to keep the project on track. At the outset of the project, during the feasibility stage, it is crucial to establish a clear schedule for budget reviews. These reviews should be conducted at regular intervals throughout each design phase. Ensuring that all key stakeholders, including the client, architect, engineers, and cost estimators, are involved in the budget review process is essential.

During each budget review, comparing the actual costs incurred to date with the original budget estimates set at the feasibility and preliminary stages is necessary. This comparison will highlight any discrepancies or variances that need to be addressed. Analyzing the reasons behind the variances, such as changes in material prices or scope creep, is crucial. By identifying these issues early, the project team can make informed decisions to mitigate their impact on the overall budget. Regular communication keeps everyone informed and aligned, facilitating timely decision-making and problem-solving.

Chapter 7

Expert Validation

Since the research was focused on the structural and architectural elements, the research incorporated an expert interview with architects and structural engineers to validate the research findings and assess their practical applicability. The choice of the interviewees was based on their practical experience in their respective disciplines and their ability to offer reflective insights into the research. This section presents an overview of the interview process, a list of interviewees, significant findings, and the feedback provided to the researcher.

List of interviewees

Table 7.1: Interviewee Codes, Positions, and Years of Experience

Associated Code	Position	Years of Experience
VA1	Architect	35
VA2	Architect	18
VS1	Structural Engineer	35

The above table shows the list of interviewees taken for the expert interview. All the experts have extensive experience within their field

7.1 Interview Procedure

The interviews were conducted with experts within Royal HaskoningDHV through Microsoft Teams. The meetings were recorded with prior consent and involved presenting the research results as outlined in the thesis. This included the current building and design processes followed, the barriers associated with the process, and the solutions and changes recommended at the end. The approach for obtaining feedback was structured, with explanations on how the results were obtained and questions asked based on the experts' experience and practical examples they provided. Feedback was collected progressively after each research segment, rather than only at the end. The feedback was gathered through questions such as "What are your thoughts on this?", "What can be improved based on your experience?", and "Is this practically possible?".

7.2 Expert Feedback and Revised Solution

While the interviewees agreed with the research results and findings, they also provided valuable feedback, recommendations, and critiques. The insights gathered from these validation interviews offer an in-depth perspective from industry experts, helping to refine and enhance the proposed solutions. The following sections detail the feedback provided by the experts during the validation interviews, offering a comprehensive view of their suggestions and observations. Following the valuable feedback and recommendations from industry experts during the validation interviews, several aspects of the initial solutions have been refined and adjusted. This section presents the corrected solutions that incorporate the insights provided by the experts.

Current Building Process and Decision-Making

All the experts agreed that the research on how the current design process works and the decision points identified are accurate. They highlighted that most decisions are made towards the end of the preliminary design phase. This feedback confirms the validity of the research findings.

Early Decision Making and Knowledge Gap

Even though the interviewees all agreed on the importance of the feasibility stage and pointed out that the beginning stages are where you can indeed have a lot of impact by making decisions early on, a lot of emphasis was given to the involvement of sustainability experts. It was pointed out as quite important to have individuals with such knowledge involved at the beginning. The client should be assisted by an expert to set realistic goals. It was also mentioned that clients often lack experience or a clear idea of what the objectives should be. Therefore, involving experts from the start can yield a significant impact on the whole project in terms of emission reduction. Interviewees also mentioned that most decisions regarding material selection are made in the preliminary design phase.

One interviewee pointed out that the green line on the graph, which represents the potential to influence emission reduction, is slightly curved but should be deeper to reflect reality more accurately. They suggested that by the definite design phase, the influence should be very low. Additionally, it was noted that the margin of error could vary when compared to real-life projects. In stage 1, the margin could be up to at least 30%. In stage 2, a 5% margin of error is very strict, and in practice, it could be around 10%, though this might differ based on the person's perspective and specific project conditions.

Revised Solution - Adjusted Margin of Error

Based on the feedback received, it became clear that the margin of error initially proposed was too strict and did not accurately reflect real-world conditions.

• Stage 1 - Margin of Error: Originally, the margin of error for Stage 1 was set at 20%, but experts suggested that in practice, this margin could realistically be around 30%. therefore adjusted from 20% to 30%, reflecting the significant uncertainties during the early feasibility stage.

• Stage 2 - Margin of Error: .For Stage 2, the margin of error was initially set at 5%, but feedback indicated that a more realistic figure would be closer to 10%. Adjusted from 5% to 10%, acknowledging that while there is still variability, it is less pronounced than in Stage 1.

These adjustments account for the uncertainties and variabilities encountered in different projects.

Revised Solution - Graph Update

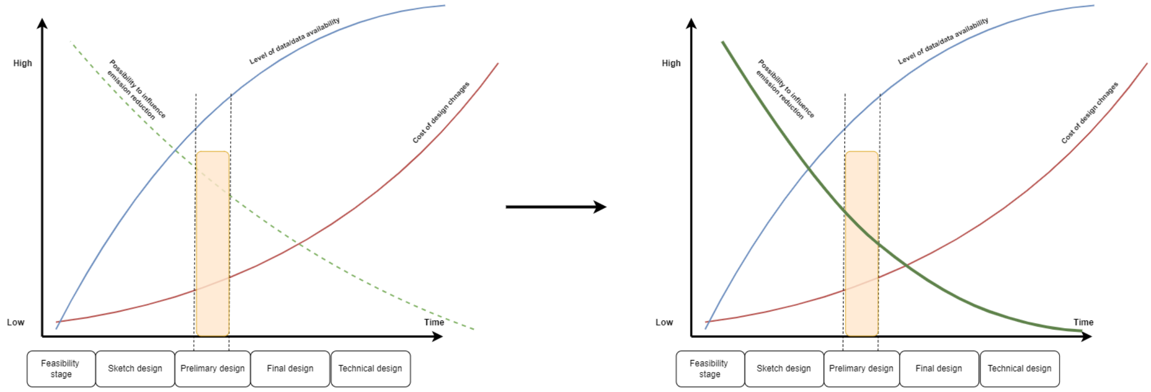

Figure 7.1: Revised graph showing the potential to influence emission reduction

The graph illustrating the potential to influence emission reduction has been revised based on expert feedback. The original green line representing the influence on emission reduction was slightly curved, but experts suggested it should be deeper to reflect reality more accurately. In the revised graph, the green line is lowered, showing a significant reduction in the possibility of influencing emission reduction by the final decision stage. This adjustment underscores the importance of making key decisions earlier in the project lifecycle to maximize the impact on emission reduction.

Transparency and Interdisciplinary Collaboration

The interviewees highlighted the importance of being transparent throughout the decision-making process and emphasized the need for interdisciplinary collaboration, noting the prevalence of issues related to the late involvement of structural engineers in projects. They pointed out that structural engineers are sometimes not involved in the early sketch design phase, which limits their ability to influence material decisions early on, highlighting the need for a more inclusive approach from the project's inception.

The interviewees stressed that material selection should be a clearly defined agenda item in project meetings to ensure it receives the necessary attention. They emphasized that without prioritizing this topic, it risks being overshadowed by other urgent matters. Having a dedicated agenda solely for discussing materials was suggested. This approach allows for an in-depth discussion with sustainability consultants. It was also suggested to not focus on the number of meetings, as certain projects and phases can extend for months, making only a few meetings unproductive. Instead, the emphasis should be on the agenda and structure of these meetings, ensuring that material selection is consistently addressed throughout the project.

Revised Solution - Graph Update

The revised validation interviews highlighted that interdisciplinary meetings are quite encouraged and common in most projects. Therefore, to enhance the material selection processes, it is crucial to make material selection a key point within these meetings and ensure the inclusion of sustainability consultants and the entire design team.

Additionally, the feedback emphasized the importance of involving all design disciplines from the beginning of the project. This early involvement ensures that material decisions are well-informed and aligned with sustainability goals from the outset. The revised solution involves an updated meeting timeline to reflect these practices and ensure continuous collaboration and focus on material selection throughout the project lifecycle.

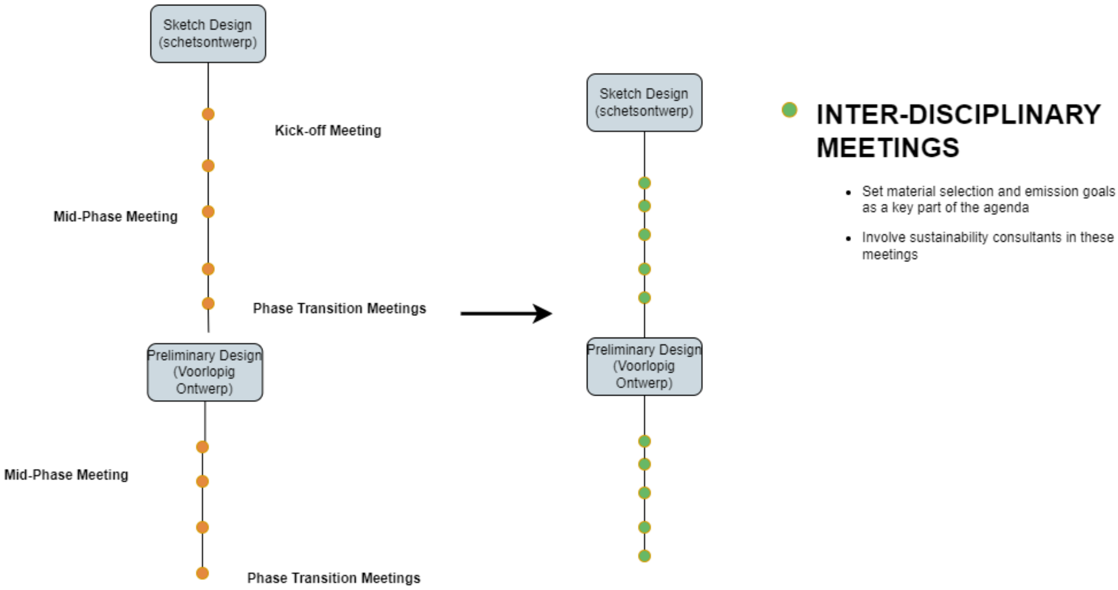

Figure 7.2: Revised structure for improving transparency in material selection

Frequent Budget Checks

The interviewees emphasized the importance of implementing frequent budget checks throughout the design phases. They noted that having regular budget checks, ideally at the end of each design phase, helps to ensure that the project remains on track financially, but it was mentioned that these checks often reveal higher costs than previously budgeted, necessitating adjustments to bring costs down. It was also noted that each phase can last several months, depending on the project's scope. Conducting checks only at the end of these extended phases may not be ideal, as it overlooks the cost changes that can occur within these months. Therefore, more frequent budget checks are necessary to stay updated with the ongoing changes. All the interviewees noted that the engineers' knowledge of the cost implications of their material choices is crucial, and having a cost engineer periodically check in on the project is valuable for maintaining budget control.

However, they also highlighted the challenge of conducting detailed budget checks due to the lack of comprehensive documentation available during project phases, as cost engineers will need some detailed drawings and specifications to make accurate budget checks, which are often not available in between project phases. So it's almost impossible for someone to see the budget or calculate the budget during these points. Therefore, it was suggested to perform price checks on individual elements as a practical approach. This helps estimate overall costs based on these prices. By extrapolating these prices as benchmarks, it becomes possible to estimate the cost implications for the project. They also emphasized the value of having cost engineers involved periodically to provide insights and ensure potential cost issues are identified and addressed early on.

Revised Solution - Frequent Price Checks

To address the challenges highlighted during the validation interviews, the revised solution involves performing price checks on individual elements as a practical approach throughout the design phases. This method allows for manageable assessments and helps estimate overall costs based on these prices. By extrapolating these prices, it becomes possible to estimate the cost implications for the project accurately.

Additionally, the revised solution highlights the periodic involvement of cost engineers to provide insights and ensure potential cost issues are identified and addressed early on. These cost engineers will conduct regular reviews at key project milestones, ensuring that the financial aspects of material choices are continually monitored and adjusted as necessary. This approach helps maintain budget control and supports informed decision-making regarding material selection, ultimately aligning with the project's financial and sustainability goals. Similarly, to address potential cost overruns, there should be a contingency plan in place. This plan can involve approaches such as value engineering to identify cost-saving opportunities without compromising quality. By implementing these measures, the project can maintain financial stability and stay on track with its sustainability goals.

Contractor Involvement

The issue of contractor involvement had conflicting opinions from the interviewees. One interview highlighted that conflicts with contractors were minimal, and from experience, most contractors they worked with were quite interested and passionate about achieving or building sustainable buildings. They noted that if the project package delivered to the contractor is clear and the goals are well-defined, contractors are likely to focus on achieving these sustainability goals rather than compromising on them. In contrast, other interviewees mentioned that contractors' agendas are often unclear and one can never know what their aim is, which can pose a challenge. However, contractors can sometimes bring valuable ideas and innovations based on their previous projects and available equipment.

The relationship between the contractor and the client also plays a crucial role; a good pre-existing relationship can enhance collaboration and project outcomes, but they also mention that this is an exception.

Chapter 8

Discussions

This research highlights the challenges the Netherlands faces with rising carbon emissions and extensive material use, with the building sector playing a significant role. Despite government efforts, embodied carbon remains a major issue. This study focuses on addressing embodied carbon in materials through the decision-making process during the design and engineering phases, where these decisions are most influential. By examining these phases, the thesis identifies and addresses the significant barriers affecting effective material selection. This chapter will discuss the entire thesis and its findings in detail.

8.1 Summary of findings

This research identified the deviations in the current decision-making processes for material selection and the critical points in these timelines. It also determined the relevant stakeholders involved and the barriers that hinder effective decision-making during the design process. Using a qualitative approach, the study revealed several key barriers, including the lack of early decision-making, knowledge gaps at the beginning of projects regarding project-specific factors, and issues related to transparency among stakeholders. The research then proposed tailored recommendations and strategies to address these barriers, focusing on improving the design process to enhance the selection of sustainable materials.

8.2 Representativeness of Interviewees

Since the research involved the construction sector and the decision-making process for architectural and structural elements, the semi-structured interviews were initially conducted with architects and structural engineers. During these initial interviews, the importance of including more stakeholders became apparent. This led to the addition of new actors such as MEP (Mechanical, Electrical, and Plumbing) professionals, material experts, and sustainability consultants. In addition to these internal interviews, interviews were conducted with two architects and a structural engineer outside of Royal HaskoningDHV. This approach broadened the scope of responses, providing insights from a wider range of the construction sector. These external interviews included professionals working at firms of varying sizes, ranging from 11-50 employees to 200-500, and large companies with up to 1000 employees.

This diversity in interviewees helped to gather input from different company sizes, from small firms to large multinationals. The findings from these interviews were generally similar across different companies, with the notable exception that smaller firms often had less expertise or fewer experts available. This variation is expected, given the differences in company size and resources

8.3 Interpretation of Results

8.3.1 Focus on the Design Process

The topic of decision-making in material selection has been widely researched, with continuous innovations and developments in decision-making frameworks such as AHP (Analytic Hierarchy Process), MCDA (Multi-Criteria Decision Analysis), and other methods of analyzing decisions (Ogunkah & Yang, 2012; Yang & Ogunkah, 2013). While similar research has been oriented around the technical capabilities and aspects of material selection decisions, this thesis specifically focuses on the design process, where major and critical decisions regarding material selection take place. There is a notable lack of emphasis on the design process and its significance in decision-making within existing literature. Additionally, there have been no attempts to create a timeline for when critical decisions regarding material selection are made. By analyzing the design process and conducting interviews with relevant stakeholders, this study has been able to outline a well-structured timeline identifying when these critical decisions occur, as compared with existing literature that only suggests making decisions early in the project is beneficial as seen in section 3.3.4.

8.3.2 Identifying Barriers

The research identified several barriers through semi structured interviews with industry professionals. These barriers were chosen because they significantly impact the decision making process for material selection in the building sector. The major findings include:

Late Stage Changes

One significant issue highlighted was the need to focus on and mitigate late-stage changes during the design process. Interviewees frequently mentioned that changes made later in the project often resulted in the abandonment of sustainable materials in favor of cheaper, less sustainable options. They attributed these late changes to inadequate planning and insufficient research during the initial stages of the project. These barriers align closely with those identified in the literature in section 3.3.4. These findings in the literature pointed out that a lack of crucial information in the early stages leads to poor planning, which subsequently results in late-stage design changes. Simply making critical decisions earlier does not resolve this issue, as it is connected to a series of related problems. For example, if early decisions are made without sufficient knowledge about material suitability within project requirements, it can lead to misdirection.

Additionally, the issue of a knowledge gap regarding material properties and project-specific data necessary for activities such as cost estimates was raised as a serious concern during the interviews. This issue was also prevalent in the literature as well as seen in section 3.3.4, where the lack of knowledge at the beginning of the project affected the ability to conduct proper Life Cycle Assessments (LCA) and accurate cost estimations.

To address these barriers effectively, the study proposes detailed recommendations focused on early stage planning and overcoming knowledge gaps.

Establishing clear objectives regarding emission goals early in the project is crucial. This should be done at the feasibility stage, with the active involvement of sustainability consultants. These consultants provide expert guidance on setting realistic and achievable sustainability goals right from the start, embedding sustainability into the core of project planning. During the feasibility stage, the project should set specific targets for reducing embodied carbon emissions, based on thorough research and aligned with industry standards and best practices. The validation with experts emphasized that early action is the most critical step in every project. They suggested setting a margin of error for these initial requirements and estimates. Initially, a margin of 20% was proposed to account for uncertainties and potential changes. However, this margin was adjusted to 30% during validation to better accommodate practical considerations and unforeseen challenges that may arise during the project lifecycle.

The study then identified a specific point in the construction process where sufficient data and information are available for making informed decisions. Reached during the preliminary design phase, this point equips the project team with the necessary knowledge to develop better strategies and set more accurate requirements. Here the experts recommended making minor adjustments to the graphs used in the decision-making process and adjusting the percentage for error to enhance the accuracy and reliability of the information, aiding better decision-making.

Enhancing Transparency

The literature study indicated that achieving effective collaboration in multi-disciplinary project environments is increasingly difficult due to poor coordination and communication among the different stakeholders involved. Several papers highlight the lack of coordination as a key factor contributing to these challenges as seen in section 3.3.6.

During the interviews, this issue was corroborated by various stakeholders. Structural engineers reported that architects and clients often made decisions affecting structural elements without involving them. Similarly, sustainability consultants mentioned that they were informed about crucial decisions later in the project, missing opportunities to integrate sustainability measures effectively. These interviews underscored the concerns highlighted in the literature, demonstrating that the lack of proper collaboration and transparency among different disciplines can significantly hinder project outcomes. Initially, it was assumed that the lack of transparency was mainly due to insufficient meetings and communication among the interdisciplinary team. Therefore the initial solutions reflected this assumption, focusing on increasing the frequency and quality of meetings. However, further validation with experts revealed a more detailed understanding. It was discovered that interdisciplinary meetings are, in fact, quite frequent throughout the project lifecycle. The primary issue was not the frequency of meetings but rather their content and the inclusivity of relevant stakeholders. Specifically, these meetings often did not include discussions on material selection and its implications. Furthermore, sustainability consultants were typically not involved in these meetings, which limited the integration of sustainable practices. Therefore it is recommended to structure interdisciplinary meetings to include discussions on material selection and emission reduction plans. By making these adjustments, a better level of transparency in the process can be achieved.

Contractor Involvement in Projects

The research also led to findings that showed conflicting or dissimilar opinions regarding the involvement of contractors in a project. Section 3.3.5 mentions the effect different contracts have on a project and how they depict the contractors' involvement. The literature's emphasizes the benefits of early contractor involvement in construction projects. Studies argue that involving contractors early allows projects to benefit from their practical experience, leading to more efficient project execution and better-informed decision-making (Song et al., 2009). Early involvement is promoted as it helps in setting realistic project goals, including emission targets and budget constraints.

However, the interviews conducted for this research presented a more conflicting view on contractor involvement. Some interviewees preferred contractors to be involved later in the project. They believed that contractors, being profit-driven, might steer the project towards their own agenda, advocating for cheaper materials that are less emission-friendly. This highlights significant differences from what is generally identified in the literature. While the literature predominantly promotes early contractor involvement, the interviews reveal that such involvement may not always be as beneficial in practice. On the other hand, several interviewees supported early contractor involvement, aligning with the literature. They argued that early involvement allows the project to benefit from the contractor's valuable practical experience. This practical insight is crucial for achieving project success, as it brings realistic and practical perspectives to the design and planning stages.

The interviewees also pointed out specific cases where early contractor involvement could be advantageous. These include situations where the client and contractor have a pre-existing working relationship or where the contractor has experience with similar projects that the design team or client needs. These circumstances suggest that involving the contractor earlier could bring merit.

Therefore, the recommendations focus on finding a suitable or ideal point to include the contractor. The proposed point is at the end of the preliminary design phase or the sweet spot identified in section 6.1.2. At this stage, the project has gathered sufficient information to set concrete targets regarding emission goals and budget constraints. The validation interviews supported this recommendation, noting that the topic of contractor involvement is quite difficult. They mentioned that one can never fully know the intentions and ambitions of the contractor, therefore it is better to be safe.

Significance of Cost

One of the most significant factors influencing a construction project is cost or budget. This was a critical point mentioned throughout the interviews. All aspects of a project are focused on and dependent on the budget. This dependency often leads to changes in decisions during a project. Although sustainability is a significant concern, most decisions ultimately depend on cost and financial feasibility. The significance of cost as a key factor is also acknowledged in the literature, specifically in the section on economic barriers. It is argued that the primary focus for clients is often on cost, pushing for cheaper and less sustainable materials.

Therefore, an accurate budget check at different phases of the design process is mandatory to ensure the project does not exceed the set budget, preventing changes to decisions later on. However, this presents a challenge. As project phases can span months to years, conducting budget checks only at the end of each phase can be ineffective, as significant changes can occur within this period. The interviewees also mentioned a lack of proper documentation during the process, which exacerbates this difficulty. To reduce this uncertainty, it is recommended to have regular price checks during these phases. A price check on individual elements that could result in higher costs can provide the project team with a better idea of staying on course. Focusing on these price checks can help maintain financial control and support the integration of sustainable materials without exceeding the budget.

8.3.3 Contextual Difference in Implementation

The research shows that the focus or the factors that affect the project the most can vary from organization to organization as well as from country to country due to numerous reasons. These include cultural differences, economic conditions, and regulatory environments. Such factors can significantly impact the implementation of the recommendations provided in this study.

For instance, as mentioned in section 3.3.2, Mohammadi et al. (2022) demonstrated how material decisions in Iran were heavily influenced by the economic conditions and recession the country was experiencing. This highlights that factors specific to a country or economic context can affect the feasibility and prioritization of certain materials and sustainability practices. Understanding these contextual variations is crucial for adapting the recommendations to different settings. For example, in countries facing economic challenges, cost-effective and locally available materials might be prioritized over, potentially more sustainable options. Conversely, in regions with strong environmental regulations and economic stability, there might be a higher emphasis on cutting-edge sustainable materials regardless of cost.

8.3.4 Variability in Graph and Data Availability

The graphs and points of influence, as well as the sweet spot developed during this research, were based on findings from the interviews and literature. However, there could be nuances that could result in slight changes in the graphs.

The Involvement of Experts Early

The involvement of experts, such as material experts and consultants, early in the project process can significantly influence the slope of the graphs. Early engagement can lead to more informed decision-making due to the knowledge they provide, resulting in the data availability slope starting at a higher point than zero. Similarly, projects involving repeated collaborations with the same team of clients, contractors, and other stakeholders can benefit from established relationships and improved knowledge and data. This early involvement is crucial for optimizing project outcomes and is supported by research indicating that early specialist involvement enhances project efficiency by leveraging their knowledge (Caron, 2014).

Impact on sweet spot

These variations in the slope affect the identification of the "sweet spot" for key decision-making points. For projects with the early involvement of experts or experienced teams, the sweet spot may occur earlier, as these projects can leverage early planning and collaboration more effectively. Consequently, it is essential to consider the specific project context, as it heavily depends on the project specifics.

8.3.5 Effect on the Design Process

Implementing the recommendations provided in this research will inevitably have various effects on the design process. Reflecting on them will help provide a comprehensive understanding of the process.

Extended Initial Phases

The early involvement of stakeholders, such as sustainability experts and material consultants, is likely to extend the initial phases of the design process. This is because these phases will require additional time for thorough planning, data collection, and early decision-making. This will increase the upfront costs of the design process. While this might prolong the initial stages, it can lead to a more streamlined execution phase, potentially reducing delays and rework later in the project. Early engagement of specialists can result in a higher starting point for data availability. These initial investments can result in long-term savings by reducing the risk of costly changes and ensuring that the project stays within budget.

Complexity

The integration of early contractor involvement in projects that follow traditional contracts will face changes and complexities. Traditional project contract systems might face difficulties collaborating with the contractor this early, as contractors typically join the project later in the process during definite design or technical design. Involving the contractor early also incurs extra costs due to their earlier involvement in the project. Changes to the interdisciplinary meeting structure will result in complexities as well. Ensuring that all relevant stakeholders, such as sustainability consultants and material experts, are included in regular meetings demands a more rigorous scheduling and coordination effort.

Cost-Benefit Balance

While the design phase costs might increase, the overall project costs could decrease due to fewer delays and changes during construction. The early identification of potential issues and the alignment of all stakeholders on project goals can lead to more efficient project execution. A detailed check during the pilot project proposed in the recommendations could result in more insight and a better understanding of the early involvement's impact.

8.4 Reflection on Findings

The implementation of the findings from the study will have a significant effect on the design process. Similarly, some of the findings can be applied more generally to affect broader aspects of the project and process. Clarifying these distinctions will help provide a better focus on them.

8.4.1 Specific Findings Relevant to Material Selection

Early Decision-Making and Expert Involvement

The research highlighted the significance of making decisions early in the design process and involving experts at this stage. This ensures that project requirements are set earlier, influencing the overall emission reduction potential and feasibility of the project. Early involvement of material experts helps in selecting materials that meet both environmental and performance criteria, thereby reducing embodied carbon emissions

Data on Material Properties

A significant finding was the need for comprehensive data on material properties. Ensuring that this data is accessible early in the project can facilitate better decision-making and material selection.

8.4.2 General Findings

Reducing Knowledge Gaps and Identifying the Sweet Spot

The recommendation of reducing knowledge gaps and identifying the sweet spot can contribute to other parts of a project. Providing data early on helps in setting planning and scheduling based on accurate information. This not only aids in material selection but also supports overall project management. Identifying the sweet spot can help in making decisions not only on material selection but on other technical aspects of the project as well.

Transparency and Collaboration

Enhancing transparency and collaboration among stakeholders can benefit the decision-making and material selection process. It also reduces conflicts and discontent among stakeholders on various aspects of the project as well. This general finding underscores the importance of effective communication and early involvement of all stakeholders, including clients, contractors, and consultants.

Frequent Budget Checks

The recommendation of having frequent budget checks results in more accurate cost estimates and reduces the chances of budget exceedance. This practice can help other parts of the project as well by minimizing cost overruns, thereby having an overall positive effect on the project beyond just material selection.

Contractor Involvement

Involving the contractor at the right time, when requirements are set, allows them to contribute their practical experience not only to material selection but also to other aspects of the project such as design and constructability. This practical experience can improve the overall project outcomes by ensuring that design decisions are feasible and cost-effective, and by anticipating and mitigating potential construction issues early in the project.

8.5 Limitations of the Study

Even though this study has contributed valuable insights, there are several limitations that need to be considered

- Initially, the study included interviews with architects and structural engineers and later expanded to include MEP consultants, sustainability consultants, and material experts. However, the research could gain additional perspectives by including more interviews with contractors and clients. This would provide a broader understanding of the decision-making processes and stakeholder influences.
- While the validation was done with experts possessing extensive experience in the field, conducting a pilot study would have shed more light on the practical application of the proposed recommendations. This would have added significant value by testing the recommendations in a real-world context, which might reveal potential weaknesses and areas for improvement.
- Similarly, the validation interviews were conducted exclusively with experts within Royal HaskoningDHV. This limited scope may introduce potential biases and restrict the generalizability of the findings. Engaging with professionals from a diverse range of companies, from small firms to large multinational corporations, would provide a more unbiased and comprehensive perspective.

Chapter 9

Conclusion and Recommendations

This section concludes the master's thesis on enhancing the decision-making process for material selection to reduce embodied carbon emissions. Through this thesis, the researcher has argued that the lack of attention to the building decision-making process has contributed to rising environmental challenges in the Netherlands, resulting in high carbon emissions. It was concluded that solutions focusing on transparency, early decision-making, and increasing the level of knowledge are important factors that need to be addressed in the landscape. The thesis, through interviews with industry professionals, researched the current building process employed in the Netherlands and the decision-making scenarios for structural and architectural elements. The aim was to identify the critical decision-making points for material selection within the design phases and to identify various barriers affecting the decision-making process. This research challenged the traditional methods currently employed in the design phase, citing their improper or poor handling of the high carbon emissions issue. By doing so, this thesis revises how material decisions are made, enhancing the decision-making process throughout the design phases.

9.1 Answering the Research Questions

Research question 1 - What is the currently followed building process in the Netherlands and how are the design phases structured within this process?

The building processes currently prevalent in the Netherlands, as well as one from a neighboring country, were analyzed to identify similarities and differences. Despite the variations in detail and execution, all the building processes shared a similar structure:

- Initiative: This phase involves the initial conceptualization and feasibility studies.
- Design and Engineering: Here the detailed design and planning occurs.
- Execution: This phase involves the actual construction based on the plans developed.
- Operation: This phase happens post-construction, this includes building operation and maintenance.

The literature provided a comprehensive account of these processes, highlighting several frameworks available in the Netherlands:

1. Basic Design Cycle
2. DNR-STB
3. NEN 2574

4. RIBA Plan of work - (*Foreign building practices*)

Each of these frameworks offers a structured approach to building projects, ensuring all critical phases are meticulously planned and executed. A detailed account of these building processes, particularly the design and engineering phases, is provided in Section 3.1. These phases are crucial as they involve critical decision-making that impacts the overall project outcome.

The exploratory interviews conducted with industry professionals shed light on the DNR-STB as the currently employed building process in the Netherlands. Developed by the Dutch Architects Association, the DNR-STB specifies in detail the tasks to be performed during the building process. This thesis focuses on the design and engineering phases within the DNR-STB, as these are pivotal for decision-making regarding material selection and reducing emissions. In the DNR-STB framework, the design phase is subdivided into several stages, each with specific objectives and deliverables:

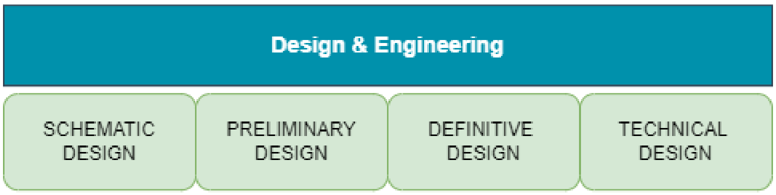

Figure 9.1: Basic Design and Engineering Phase

Research question 2 - Who are the stakeholders involved in the decision-making processes for material selection?

Identifying the stakeholders involved in the material selection decision-making process is vital for understanding how these decisions are made. Each stakeholder's choices impact the overall decisions, and their influence on the selection process varies depending on their roles and interests. To gain a comprehensive understanding, a literature review was conducted to identify the key stakeholders involved in the decision-making process. Following this, semi-structured interviews were carried out with major stakeholders, particularly architects and structural engineers, as the focus was on architectural and structural elements. These interviews also helped identify new stakeholders with significant interest or influence on the process.

The stakeholders identified through this research are detailed below:

- Client: The client or project owner is the primary stakeholder whose requirements and budget constraints significantly influence material selection.
- Architect: The architect plays a crucial role in material selection, balancing aesthetics, functionality, and sustainability.
- Structural Engineer: The structural engineers ensure that the materials meet the necessary strength and building code standards required.
- Government and Regulatory bodies: The Government and Regulatory bodies set and enforce the building codes and other mandatory regulations that guide material selection.
- Contractor: The contractor is responsible for executing the design and has a say in the material decision based on their practical experience.
- MEP Engineer (Mechanical, Electrical, and Plumbing): The MEP engineers influence material selection through the MEP elements (HVAC, wiring, and plumbing). these elements must be compatible with the other designs to ensure seamless integration.
- Sustainability consultants & Expert on Material Properties: These stakeholders provide detailed knowledge about material characteristics, performance, and practices to minimize the building's

carbon footprint and enhance sustainability.

Research question 3 - How are current decisions in material selection for architectural and structural elements structured during the design phase and at what stages of the project do these processes typically occur?

Each design phase can span for several months, depending on the project. Therefore, understanding how and when decisions regarding architectural and structural elements are made within these phases are essential for this research, as it highlights the major areas of decision-making and influence within the process. To gain a detailed understanding, semi-structured interviews were conducted with the identified stakeholders, providing deep insights into how and when each of them selects materials and how these choices affect sustainability and other design elements. In Section 4.2, a detailed review of each design phase and the major decisions occurring in these stages is provided. Notable decisions made in each phase are explained below:

- Sketch Design: In this initial phase, the design team identifies the project's key requirements based on the client's ambitions and brainstorms initial ideas and possibilities. This stage is crucial for setting the overall direction and vision of the project.
- Preliminary Design: Actual decision-making begins at this point. The team analyzes which materials and structures are best suited based on the project's requirements. By the end of the preliminary design phase, the design team has thoroughly researched and identified specific materials for consideration.
- Definite design: In this phase, decisions are finalized, and more detailed aspects such as dimensions are set. A final cost calculation is also performed. In most projects, the tendering stage is initiated after the definite design to include the contractor during the technical design phase.
- Technical design: During the technical design phase, all designs are finalized. In a traditional project, the tendering process typically starts at the end of the technical design phase. This stage ensures that all technical specifications are in place, facilitating a smooth transition to the construction phase.

Each of these phases involves critical decision-making points that significantly impact the project's sustainability and overall design. By understanding these phases and their respective decision points, this research sheds light on how material selection processes are structured and highlights opportunities for reducing emissions.

Research question 4 - What are the key barriers influencing the decision-making process in material selection regarding emission reduction?

To effectively enhance the decision-making process, it is vital to understand the prevalent barriers that affect decision-making and inhibit the reduction of emissions throughout the process. To gain better insight into these existing barriers, a qualitative approach using a narrative literature review was conducted, where the research compiled and connected various sources by a common theme. In addition, semi-structured interviews were conducted with various stakeholders involved in the current process. The most important barriers identified are outlined below:

- Lack of Early Decision Making: A significant barrier faced during the design process is the inability to make well-researched or thought-out decisions early in the process. Numerous studies have highlighted that the early stages of a project are when one has the maximum amount of influence over the process and is encouraged to make critical decisions at this point. Once a project progresses towards the later stages, it becomes much more expensive and difficult to make such decisions. This barrier mainly stems from two reasons:
    1. Lack of Knowledge, Expertise, and Reliable Information: There is an apparent gap in

the level or amount of accurate data available in the earlier phases of a project. These incomplete information gaps can lead to poor or subpar material decisions.

2. Inadequate Early Project-Specific Information: During the initial stages of a project, data concerning the project is quite limited. This issue arises from various factors, such as the lack of detailed project requirements and poor initial cost estimates.

- Transparency: The interviewees highlighted issues such as a lack of transparency within the multidisciplinary team and communication barriers. Similarly, research also shows that the absence of proper transparency and collaboration leads to inefficient decision-making in such projects. Each discipline's decisions significantly affect others, making it crucial to acknowledge and address these transparency issues to improve overall efficiency.

- Contractor Involvement: Involving contractors in the design phases is a crucial factor impacting material selection. When the contractor is involved earlier in the project, their practical experience can significantly benefit the project by providing valuable input. However, this involvement can also pose challenges. Contractors, aiming to increase their profit margins, might influence material selection towards cheaper options or materials they are familiar with, rather than innovative, emission-friendly alternatives. Conversely, if contractors are brought into the process later, they cannot influence the decision-making process towards their preferences. While this might prevent biases towards cost-saving measures, the project misses out on their practical insights and expertise on material selection.

- Late-Stage Design Changes: Changes to design and material decisions later in the design stages, such as during the definite design phase, present significant barriers. These changes typically occur due to the following reasons:

  1. Infrequent Budget Checks: Cost overruns are a prevalent issue in most projects. Studies show that 75% of projects experience a cost overrun, often exceeding 90% of the initially set budget. This overspill of costs is often due to the lack of frequent budget checks during the design phase. When budget checks are performed late, the realization of budget overruns is often delayed, leading to necessary changes in design and material selection to align with the available budget.

  2. Late Changes Due to Inadequate Initial Planning: Poorly designed initial planning is another reason for changes later on. When a project fails to set quality standards, goals, and requirements early on, discrepancies can arise between the final design and the actual project requirements. Without specific, well-defined goals, projects may need to make significant adjustments late in the design phase to meet the necessary standards and requirements.

Research question 5 - Based on identified barriers, what recommendations or strategies can be made to enhance the material selection process?

The earlier identified barriers pose a serious threat to the design phases and the material selection process. To mitigate these barriers, this research has proposed several detailed recommendations that need to be implemented within the project. They are detailed below:

1. Early Decision-Making with Knowledge Gap Reduction: This recommendation aims to tackle the issue of delayed decision-making in the early stages of a project and the lack of project-specific knowledge. A two-stage solution is proposed:

   Stage 1 - Establishing Emission Objectives Early:

   In this stage, the main aim is to set goals and objectives regarding emission requirements early in the project during the feasibility phase. This phase provides an opportunity for the client and sustainability consultants to define their goals and convert their ambitions into achievable targets and requirements for the project. It is vital to have a sustainability consultant at this stage, as they have the necessary knowledge to engage the client and set realistic expectations. Setting such requirements early will help the project move forward with a higher level of understanding. The critical points for consideration at this stage include:

- Define Objectives: Clearly define the objectives or targets that the project wants to achieve, in close collaboration with sustainability consultants and clients.
- Develop Strategies: Develop well-defined strategies to achieve the set requirements and goals. This step involves identifying different methods to realize the objectives.
- Cost Budgeting: Since cost governs almost all decisions in material selection, it is imperative to have a realistic estimate of the resources required to implement the devised strategies.

Following these steps will help set realistic goals and achieve them. Although these steps aim to eliminate many concerns, there is still a margin of uncertainty at this early stage, considered to be 10% to 20%.

Stage 2 - Reducing the Margin of Error

This stage aims to reduce the margin of error identified in Stage 1. The main cause of the margin was the lack of project-specific data at an early phase. Therefore, the research identified a critical area of influence within the early stages, referred to as the "sweet spot," where the project achieves three main criteria:

(a) Possibility to Influence Emission Reduction: The sweet spot should be a point where there is sufficient influence to reduce emissions.

(b) Cost of Design Changes: The point should allow changes in the design with lower costs and lesser impact.

(c) Level of Data: The project should have acquired a sufficient level of data to make more informed decisions.

Through the interviews conducted, the sweet spot where all three criteria were achieved was identified as the preliminary design phase, approximately between the "Design Principles at 40%" and "Concept at 90%" stages.

Setting Final Requirements:

Based on the identification of the sweet spot, it was recognized where the most critical point of influence for material selection in a project is. The feasibility report will be employed once again where the objectives, strategies, and cost budgeting will be confirmed. This time, these steps are set in stone with no room for changes, reducing the margin of error to 5%-10%, thanks to the availability of project-specific data at this point.

2. Ideal Phase for Contractor Involvement: From the earlier analysis of the sweet spot, it is evident that at this critical stage, the project has gathered enough data on materials, cost implications, and other project-specific factors. Therefore, involving the contractor post this sweet spot will be ideal. During this stage, the project team can set clear requirements and detailed clauses regarding emission goals in the contract, ensuring that the contractor is aligned with the project's ambitions. Involving the contractor in this phase will also provide the opportunity to offer valuable practical input to the project.

3. Enhancing Transparency and Interdisciplinary Collaboration in the Design Process: To facilitate higher and more effective project outcomes, effective collaboration within the multiple interdisciplinary teams is essential. Therefore, it is recommended that during the numerous multidisciplinary meetings held during a project, the topic of material selection should be highlighted in the agenda. Additionally, sustainability consultants should be included in these meetings to ensure that emission control is addressed.
4. Frequent Budget Checks: The research has highlighted the lack of proper budget checks throughout the project, often resulting in cost overruns. Therefore, it is suggested to conduct frequent budget checks periodically throughout the project. Additionally, performing price checks on individual elements will help the project gain an estimate of the cost implications when major changes are made during the phases.

9.2 Recommendations for Royal HaskoiningDHV

The research has identified several barriers that Royal HaskoningDHV faces in achieving emission reduction within their projects. This section provides practical guidelines and strategies to efficiently implement the recommendations in a practical setting.

Transparency

Achieving transparency among the various individuals and employees working together on a project is crucial to accomplishing any goal or ambition. Without a proper plan to address transparency and collaboration issues, it would be futile to focus on other challenges.

- The first step is to acknowledge that there is a problem regarding transparency. Promoting transparency and collaboration should be a core part of every project. Recognizing and addressing this issue is fundamental to fostering a collaborative work environment.
- Ensuring that every discipline is well-informed about all activities and changes occurring in the project is essential. No action that affects other disciplines should be taken without their consultation. This inclusive communication approach helps prevent misunderstandings and ensures that all team members are on the same page.
- Organizing regular interdisciplinary meetings with a structured agenda that includes emission reduction as a key topic is crucial. These meetings should involve key stakeholders such as sustainability consultants and ensure that every discipline has the opportunity to contribute and share their insights. By including all relevant stakeholders, the project can benefit from diverse perspectives and expertise, leading to better decision-making and project outcomes.

Early Stage Planning

Taking control of the project early is crucial. In the initial phases, sustainability consultants should actively engage clients in setting their ambitions and sustainability goals. A detailed framework could be developed to guide this early engagement, ensuring that clients are involved in setting clear and achievable objectives from the outset. The requirements set at this phase will shape the rest of the project and its structure, making early decision-making and consultant involvement vital. Similarly, the inclusion and development of material experts are also crucial, as their expertise is essential to the process. When the project reaches the preliminary design phase, a thorough review of the project's goals and objectives should be conducted to ensure they are achievable within the proposed budget. If not, these goals should be refined to match realistic targets. This approach helps the project stay on track and mitigates the risk of late-stage changes.

RHDHV should keep in mind that the requirements and criteria set are all under a margin of error and can change. Encouraging and implementing continuous learning and training programs for staff to stay updated with the latest advances in emission-friendly materials is also essential to close this gap.

Regular Budget Checks

Royal HaskoningDHV should ensure that every project adheres to a strict and structured budget check policy. Regular price checks on individual elements that could significantly impact the project's budget should be conducted throughout the project lifecycle. This practice will help maintain financial control and ensure that the project stays within budget.

Delegating this responsibility to an individual, such as a cost engineer, can help manage and monitor these changes effectively. The cost engineer's role would be to continuously check and keep up with any changes in the project, ensuring that the financial aspects are tightly controlled and aligned with the project's goals.

Setting Requirements

In every project, setting requirements in terms of the project's emission objectives as well as budget constraints should be explicitly mentioned at the end of the preliminary design phase. This helps the project to have concrete goals to move towards, and including these requirements in the tendering documents ensures that contractors are aware of the emission and budget constraints from the outset, promoting adherence to sustainability goals and financial limits throughout the project lifecycle.

Implementation Strategy

The recommendations can be implemented through an initial or preliminary pilot project. This allows Royal HaskoningDHV (RHDHV) to test, refine, and integrate feedback in a controlled environment. It also provides an opportunity to identify potential challenges and areas for correction or improvement before implementing on a larger scale.

Monitoring and evaluation of the pilot projects are critical to guide full-scale implementation. The steps that need to be taken are:

1. Develop and design KPIs to measure the success of each recommendation with respect to its objectives (Kusek & Rist, 2004). KPIs provide a clear framework for assessing whether the goals are being met and allow for objective measurement of progress. The KPIs should align with the project objectives and could include:
    - Number of interdisciplinary meetings held where emission reduction was a key topic.
    - Frequency of budget checks.
    - Extent to which emission reduction goals are met and projects stay within budget.
    - Number of projects where detailed requirements are included in tenders.
2. Add Milestones to regularly review the progress of pilot projects and assess progress by documenting lessons learned (Lock, 2017). Milestones help track progress, ensuring that the project remains on schedule and that any issues are addressed promptly.
3. Collect feedback from project teams and stakeholders to identify areas for improvement (Kusek & Rist, 2004). This feedback is crucial for refining the process and making necessary adjustments to improve outcomes.

9.3 Recommendations for Future Research

1. The research primarily concentrated on the design process aspects, with less emphasis on technical aspects such as maintainability and constructability. This was a deliberate choice to narrow the focus of the study. However, a broader approach that includes these technical aspects might provide a more comprehensive understanding of the research problem. A more detailed study that also considers technical factors such as the availability of resources and constructability could show other important areas and present a more holistic view.

2. A case study method of qualitative research could provide more narrowed-down analysis by interviewing stakeholders involved in a particular project. This approach would help in understanding how decisions are made within specific projects and offer a more complete picture of the decision-making scenario.

3. The MPG methodology does not adequately account for the potential reusability of materials such as wood, leading to a biased assessment favoring traditional materials like concrete and steel. Future research should focus on developing detailed scenarios that accurately reflect the potential for biobased materials to be reused at the end of their lifecycle. This includes examining conditions and factors affecting the reusability of materials like wood, such as the loss of strength and integrity over time. Understanding how these materials can be effectively reused in new construction or other applications is crucial, including identifying any additional impacts or savings associated with their reuse.

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Appendix A

Interview Protocol

Introduction

Who am I

My name is Nikhil, and I'm a graduate student at TU Delft. I'm working on my thesis titled, "Enhancing the Decision-Making Process for Material Selection: Strategies for Reducing Emission."

What I will do with your information?

Regarding the anonymity of the report, I have shared a checklist detailing what data will be used and what will not. This interview will be recorded and transcribed, but all data will be anonymized. Nothing said during the interview, including names, will be included in the report, and all data will be deleted after the thesis is completed.

- **Exploratory Interview Protocol**

Why is this person here?

You are a project manager with many years of experience in the construction sector, and I am conducting this interview to gain insights into the current building process in the Netherlands and how it is structured.

Questions and guiding themes of the interview

This interview will consist of exploratory, open-ended questions aimed at understanding the current building processes used in the Netherlands and the different stages and phases involved.

Questions

1. Could you provide a comprehensive overview of the standard design process in your construction projects?
2. Can you describe the current process in detail?
3. What are the differences between theory and practice?
4. What are the major changes that can occur during the building process?
5. Who are the key stakeholders in the design process and what roles do they play?
6. What are the major decision points in the design process?
7. How does the contract type affect the design process?
8. Are the current design phases, such as DNR STB, adequate to handle current developments?

9. What are the significant challenges in the current design process, specifically with DNR?
10. How is feedback incorporated into the design process?
11. What improvements or changes would you recommend to improve the current design process?
12. Why has the design process not been updated despite existing issues?

Closing Remarks

Are there any additional comments or topics you think are important to discuss regarding the building process and material selection in the Netherlands? -Thank you for your time and insights.

- **Semi-Structured Stakeholder Interview Protocol**

Why is this person here?

You are being interviewed because of your role as a key stakeholder (e.g., architect, sustainability engineer, MEP consultant, sustainability consultant, or material expert) involved in the construction industry. Your insights are valuable for understanding the current decision-making process and identifying factors or barriers that affect it.

Questions and guiding themes of the interview

This interview will consist of semi-structured, open-ended questions aimed at understanding the decision-making process for material selection in construction projects, focusing on factors, barriers, and considerations related to emission reduction and efficiency.

Understanding the Building Process (DNR-STB)

My research focuses on the decision-making processes for facade and structural elements within construction projects. To facilitate a more detailed and focused discussion, it would be helpful if you could think of a specific project you have worked on that involved key decision-making moments within the design process, especially in relation to material selection for both facade and structural components. I will also attach an image of the design process for your reference.

Questions

1. Thinking about the project you have in mind, could you describe the overall scope and the key objectives related to material selection?
2. For the structural elements in this project, when did the decision-making process begin? Can you walk me through the steps from initial consideration at sketch design to final decision?
3. What were the key factors that influenced this selection?
4. Who are the key stakeholders involved in material selection?
5. To what extent is emission reduction considered during material selection in each phase? In what ways are these considerations integrated?
6. When is the MPG (MilieuPrestatie Gebouwen) criteria considered in the material selection process?
7. Based on your experience, what are some key factors, barriers, and drivers affecting material selection?
8. What improvements or changes would you recommend for optimizing the design process, particularly to enhance emission reduction and efficiency?

Closing Remarks

Are there any additional comments or topics you think are important to discuss regarding the decision-making process and material selection in the construction industry? Thank you for your time and insights.

****Note:** While these interview questions are general, they are tailored towards each stakeholder group. For instance, questions for sustainability consultants, MEP consultants, and material experts are adjusted to focus on their specific expertise and field.**

- **Validation Interview Protocol**

Why is this person here?

You are being interviewed because of your extensive experience (close to 30 years) in the construction industry. Your expertise is invaluable for validating the findings of my research.

Questions and guiding themes of the interview

This interview will consist of semi-structured, open-ended questions based on the findings of my research. I will walk through each finding, gaining your opinion on its practical implications and implementation in practice.

Questions

1. I will present one of the findings from my research. What do you think about this finding?
2. What is the practical implication of this finding in the construction industry?
3. Have you faced a similar issue or scenario in your experience?
4. Here is a barrier identified in my research. What are your thoughts on this barrier?
5. Do you agree with this barrier as a significant challenge in the field?
6. Can you provide examples from your experience where this barrier was evident?
7. I have proposed a solution/recommendation for a specific issue. How do you perceive the feasibility of this solution in practice?
8. Do you think this recommendation would be effective in the current construction processes?
9. Are there any potential challenges or obstacles to implementing this solution?
10. Based on your experience, what would be the practical steps to implement this finding or recommendation in a real project?
11. Are there any modifications or improvements you would suggest to make this more applicable in practice?
12. Do you have any feedback on the overall findings of my research?

Closing Remarks

Are there any additional comments or topics you think are important to discuss regarding the findings and their practical implications in the construction industry? -Thank you for your time and valuable insights.

- **Consent Form**

The participants were presented with a consent form stating the purpose of the interview as well as regarding their anonymity and storage of the data, a sample of the form is provided below.

Delft University of Technology
HUMAN RESEARCH ETHICS

INFORMED CONSENT

You are being invited to participate in a research study titled "Enhancing the Decision-Making Process for Material Selection Towards Emission-Free Building." This study is being carried out by Nikhil Varghese of TU Delft. The purpose of this research study is to develop solutions and recommendations for enhancing the decision-making process for material selection in building projects in the Netherlands, focusing on sustainability and emission reduction. This is done by investigating the current building and design processes, particularly in collaboration with Royal HaskoningDHV.

To gather the related information, you will be asked to participate in an online/offline interview of up to 60 minutes. The gathered data will be used for master thesis research only. You will be requested to provide your understanding and perspectives on material selection and sustainability practices in construction.

Your participation in this study is completely voluntary, and you can stop participating at any time. You are also free to leave questions unanswered. As with any online activity, the risk of a breach is always possible. To the best of our ability, your answers in this study will remain confidential. We will minimize any risks using the following means: the audio/video of the interviewees will be recorded just for transcribing the information into text. This recording is only accessible to the main investigator (Nikhil Varghese) who conducts the interview and will not be shared further. The transcribed information can only be accessed by the research team. After completion of the master's thesis, the recording and the transcripts will be permanently deleted. In addition, all information you provide is anonymized, which means that your name or contact details are not mentioned in quotes or transcripts, among other things. You may also rectify or delete the information immediately after the interview or request to review the transcript.

The aggregated anonymized information will be shared in the master thesis that will be uploaded to the TU Delft Education Repository, as required for inspection and possible further research, but will not contain any personal data that could identify you. No personal data will be shared outside the research team and will therefore not be mentioned in the master's thesis.

Below you can find the informed consent form of the research. Please tick the boxes to indicate your consent. For further information, questions, or comments, please send an email to Nikhil Varghese (n.s.varghese@student.tudelft.nl).

Figure A.1: Sample consent form

Appendix B

DNR-STB

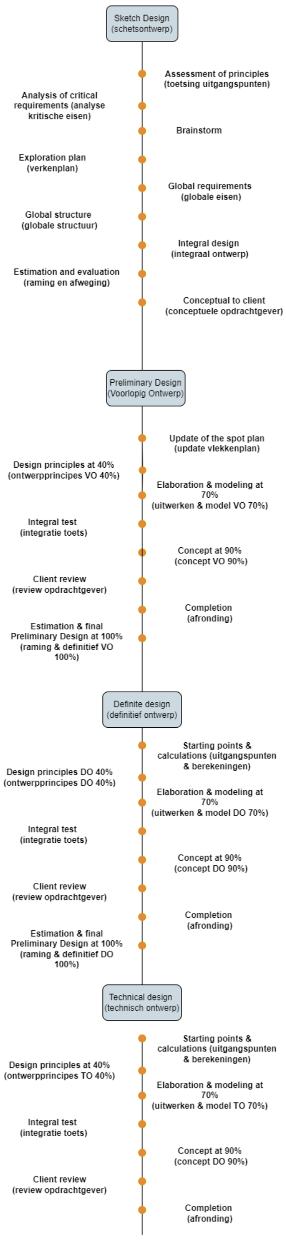

Figure B.1: Detailed DNR-STB, Source: Anton, Royal HaskoningDHV (2024)

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