Managing The Real Estate Development Paradox

Developers' management of the paradox between profitability and embodied carbon reduction

P5

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Preface

The concept of sustainability has been a critical component of my studies in the built environment discipline at TU Delft. One important realization I've had is the need for balance in sustainability. Overemphasis or overindulgence in one area sometimes leads to neglect and degradation in others. As a result, attaining balance was a major emphasis of my master's thesis.

During the process of writing this thesis, I learned an important lesson from a recommended book (Bright, 2019): “Wilbert the Whale is always looking for more stuff because deep inside he feels a hole. But all those things don't make him happy. Wilbert has to find something that will make him happy, but what?”. If I reflect on this in my research, it is important to find a way to make the planet a better place by building net-zero developments instead of just building everything you want to build. So don’t just build a building but try to make the planet and the users on the planet more eco-friendly and comfortable.

I express my heartfelt gratitude to my supervisors, Erwin Heurkens and Angela Greco, for their essential mentorship and the trust they have placed in me. I also want to thank my graduation firm NEOO, particularly Rogier Claassen, for the valuable and practical teachings provided during our sessions, as well as the independence I was given to pursue my studies. Despite their rigorous timetables, I always feel bolstered and never had a deficiency of aid.

My goal for this thesis is to be useful to developers, assisting in the faster achievement of net-zero carbon goals.

Tom Oskam

Amsterdam, june 2024

Abstract

Abstract – There is a growing emphasis on reducing the amount of carbon that is embodied in buildings, a huge contributor of greenhouse gas emissions is the real estate sector. Despite this, a number of challenges, primary among them economical limitations, obstruct the advancement of meaningful carbon reduction. Interestingly, there is an absence of research that focuses on these financial issues from the perspective of developers, and what little study there is sometimes lacks thorough analysis and practical answers. Reevaluating developers' investment decision-making is crucial, especially in light of the industry's recognition of the need of reducing carbon emissions, especially with regard to embodied carbon. But incorporating these fresh viewpoints into useful models is still a challenging task. Therefore, *"How can developers manage the paradox between profitability and embodied carbon reduction?"* is the research question.

By answering this question, knowledge of the ways in which developers' perspectives are influenced by financial factors when integrating embodied carbon reduction strategies into investment decision-making is improved. The goal of this study is to guide developers and the broader system surrounding this subject to profitable Paris Proof projects. This change is anticipated to enable the installation of new, ecologically friendly dwellings while considerably lowering the building and construction sector's carbon footprint.

Keywords – Embodied carbon, developers' decision-making, paradox, business case, life cycle assessment, reduction strategies, and regulations

Executive summary

Introduction

The urgency of climate change and the need for sustainable urban development has become critical. The built environment significantly contributes to global greenhouse gas emissions, with the real estate sector responsible for 40% of these emissions. This thesis, titled "Managing the real estate development paradox: Developers' management of profitability and embodied carbon reduction," explores the balance between profitability and the reduction of embodied carbon in real estate development, addressing the paradox of achieving net-zero carbon developments while maintaining economic viability. A conceptual framework makes the relationships between the problems more visual.

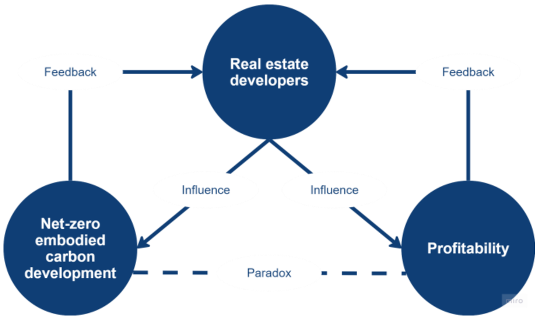

Figure 1: conceptual framework (Own illustration)

The real estate sector faces the challenge of adhering to stringent sustainability regulations and addressing the national housing shortage in the Netherlands. Despite the clear need to reduce carbon emissions, the practical integration of embodied carbon reduction strategies into profitable business models remains a significant challenge. Thus the main research question is:

<u>How can developers manage the paradox between profitability and embodied carbon reduction?</u>

The sub-questions that help answer the main research question are:

1. How can embodied carbon in real estate development be assessed?

2. Which regulations for embodied carbon in building projects are in place now and may be implemented in the future, and which ones could affect the decision-making of developers?

3. What strategies are currently available to developers to reduce embodied carbon in their projects and how are they used in practice?

4. How much does the consideration of reducing embodied carbon factor into the decision-making process of developers in present practice?

5. What modifications do developers make to the business case parameters to implement strategies aimed at reducing embodied carbon?

Research method

Research Design

The research design combines both theoretical and empirical approaches to address the main research question. The study employs a mixed-methods approach, integrating qualitative and quantitative data to provide a comprehensive understanding of how developers can manage the paradox between profitability and embodied carbon reduction. The research design is structured into components: theoretical research, empirical research, and synthesis.

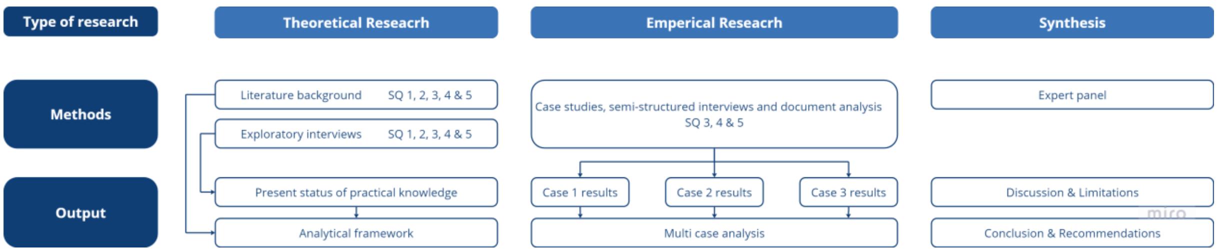

Figure 2: Research design (Own illustration)

Theoretical Research

The theoretical research aims to define the main concepts and broaden the theoretical background of the study. This component addresses the first two sub-questions:

1. How can embodied carbon in real estate development be assessed?
2. Which regulations for embodied carbon in building projects are in place now and may be implemented in the future, and which ones could affect the decision-making of developers?

To answer these questions, a comprehensive literature review was conducted, focusing on four key concepts: embodied carbon, regulations, developers decision-making, and business case parameters. Various sources were used, including academic journals, government documents, and industry reports. Exploratory interviews with industry experts provided practical insights and helped validate theoretical findings.

Empirical Research

The empirical research component addresses the remaining sub-questions:

3. What strategies are currently available to developers to reduce embodied carbon in their projects, and how are they used in practice?
4. How much does the consideration of reducing embodied carbon factor into the decision-making process of developers in present practice?
5. What modifications do developers make to the business case parameters to implement strategies aimed at reducing embodied carbon?

This component utilizes case studies and semi-structured interviews to gather practical data. Three case studies of Dutch real estate projects: Populus, SAWA, and Koelmalaan were selected based on their relevance and implementation of embodied carbon reduction strategies. Semi-structured interviews with key stakeholders in each project, including developers, and architects provided in-depth insights into the decision-making processes and practical challenges faced during project implementation.

Synthesis

All findings of the previous sub-questions are used to create a comprehension between the theoretical research and the empirical research. A validation of the drawn conclusions are being tested by an expert panel. An expert panel is a gathering in which a group of specialists attempt to establish agreement on a certain issue via debate (Slocum-Bradley, 2003). This expert panel consists of four real estate developers who help test and define the framework for actual use in real practice.

Theoretical research

For the theoretical research the focus is on four key concepts: embodied carbon, regulations, developers' decision-making, and business case parameters.

Embodied Carbon

Embodied carbon refers to the carbon emissions associated with the entire lifecycle of a building, from material extraction to demolition. The lifecycle emissions consist of two main components: operational and embodied emissions. While operational emissions have been extensively studied and addressed, embodied emissions are becoming increasingly significant. This study defines embodied carbon as the carbon emissions that occur throughout the process of extracting materials, production, transportation, construction, maintenance, and end-of-life stages of a building's lifecycle. To assess embodied carbon, methodologies such as Life Cycle Assessment (LCA) are utilized, which quantify the carbon footprint of materials and construction processes.

Regulations

Regulations related to embodied carbon are critical in shaping the strategies and practices of real estate developers. The study reviews existing regulations at both European and national levels. Key regulations include the European Green Deal, which aims to reduce carbon emissions by 55% by 2030, and the Dutch Green Building Council's (DGBC) Paris Proof targets, which set stringent limits on carbon emissions for new developments. Additionally, the Energy Performance of Buildings Directive IV (EPBD IV) mandates operational carbon neutrality for new buildings by 2028. These regulations influence developers' decision-making processes by setting legal requirements and providing frameworks for achieving sustainability goals.

Developers' Decision-Making

The decision-making process of developers is complex and influenced by both financial and non-financial factors. This study examines how developers incorporate sustainability considerations, particularly embodied carbon reduction, into their decision-making processes. The research identifies key decision-making activities, including recognizing and identifying problems, establishing decision-making criteria, searching for information, assessing risks and options, making decisions, and monitoring and reassessing outcomes. Understanding these processes helps in identifying how developers can effectively balance profitability with sustainability goals.

Business Case Parameters

Business case parameters are essential for evaluating the financial viability of real estate projects. This study explores how embodied carbon reduction strategies impact various business case parameters, such as cost, revenue, return on investment, and risk. By examining case studies and conducting interviews with industry experts, the research identifies modifications that developers can make to their business models to integrate embodied carbon reduction without compromising profitability. These parameters are crucial for developers to justify investments in sustainable practices and align them with broader economic goals.

The conclusion of the theoretical research has been put into an analytical framework that serves as the basis for the empirical research.

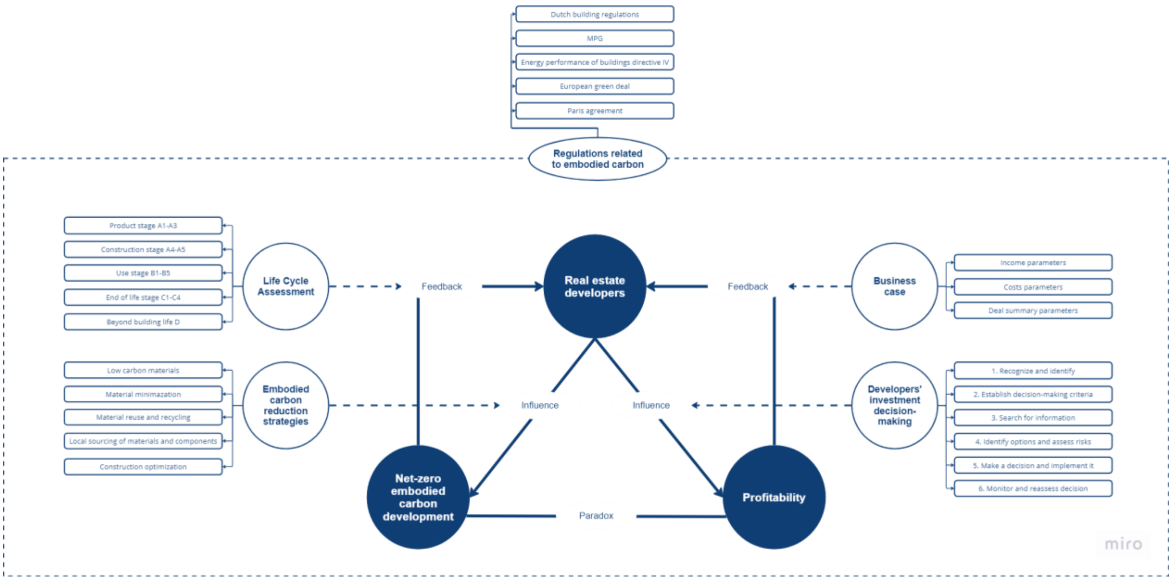

Figure 3: Analytical framework (Own illustration)

Empirical Research

Case studies and the multi-case analysis reveal the practical application of embodied carbon reduction strategies and their financial implications. Each project demonstrates unique challenges and solutions. The cases that are used are Populus, SAWA, and Koelmalaan. During the multi-case analysis, several key takeaways came forth that developers can implement to manage the paradox. These key takeaways are:

- Holistic Area-Level Sustainability Planning
- Innovative Construction Methods
- Stakeholder Engagement
- Balancing Strategies Against Long-Term Benefits
- Hybrid Construction Solutions
- Engagement in Carbon Credit Markets
- Negotiating Improved Financing Terms
- Leveraging Accelerated Timber Construction
- Comprehensive Database for Materials
- Standardized CO2 Tracking Tool
- Regulatory and Policy Frameworks
- Investment in Knowledge and Skills
- Market Demand for Sustainable Living Spaces
- Implementation of Carbon Pricing
- Subsidies for Sustainable Practices
- Local Sustainable Material Production
- Streamlining Sustainable Supply Chains

Expert panel

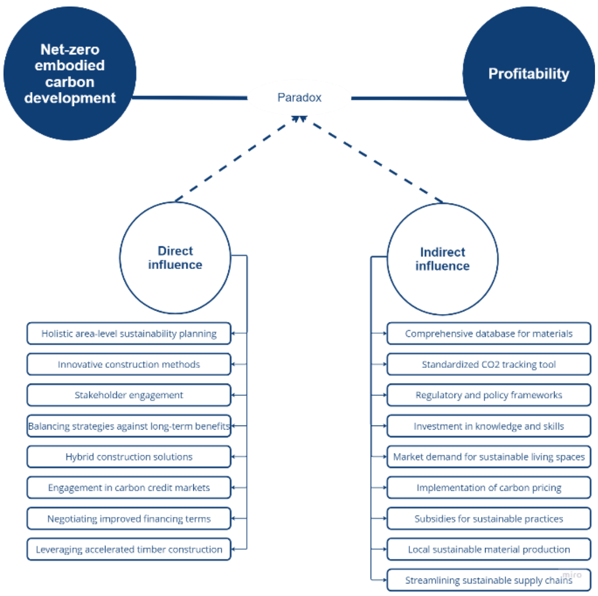

Figure 4: Paradox framework (Own illustration)

The key takeaways from the multi-case analysis are validated with an expert panel. In the expert panel came forth that developers have different influences on these key takeaways. That's why the key takeaways are split into two; direct influence and indirect influence. Four real estate developers were chosen based on their experience in sustainable development and their active roles in the Dutch real estate market. Their expertise and practical insights were crucial for evaluating the feasibility and impact of the identified findings. Summaries of the key takeaways from the multi-case analysis were prepared, highlighting both direct and indirect influences.

Conclusion

To balance profitability and embodied carbon reduction in real estate, developers should use low-carbon materials despite higher upfront costs. Strategies like material reduction, modular construction, and local sourcing improve resource efficiency and can enhance economic returns. Effective stakeholder engagement and participation in carbon credit markets can offset initial expenses. Supportive structural changes, including consistent regulatory frameworks, comprehensive CO2 monitoring systems, and government incentives, are crucial. By integrating sustainability into core processes and leveraging financial incentives, developers can achieve both environmental and economic benefits.

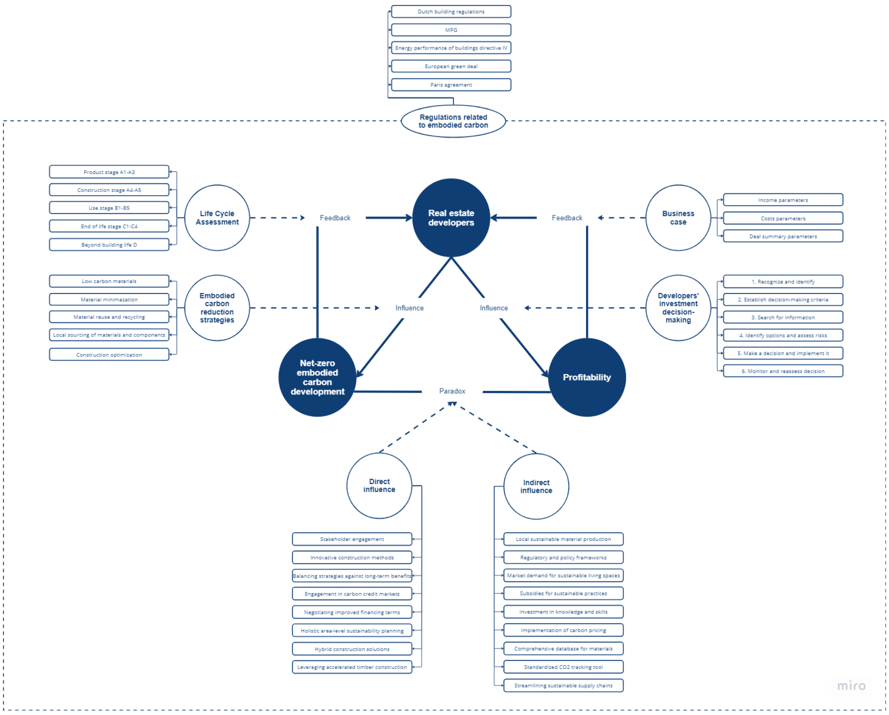

Figure 5: Framework to manage the paradox between profitability and embodied carbon reduction (Own illustration)

Table of contents

List of figures

List of tables

Chapter 1

Introduction

1 Introduction

As humanity deals with the consequences of accelerated climate change, sustainability transitions in urban developments have become a global imperative. The contemporary era, characterized by rapid urbanization and escalating ecological degradation, necessitates innovative approaches to create resilient and sustainable urban landscapes. The built environment is a substantial contributor to global environmental changes. Cities, the epicenters of human activities, hold the key to mitigating environmental impacts and fostering sustainability (IPCC,2019; Ahmed et al., 2022). The Architecture, Engineering, and Construction (AEC) industry is poised at the crossroads where the transformation for sustainability is imperative. A famous Native American proverb told by numerous speakers, "We do not inherit the earth from our ancestors, we borrow it from our children". Echoing this sentiment, the AEC industry needs to imbibe sustainable practices to ensure the legacy left behind is not marred by ecological devastation. The pressing need to integrate sustainable solutions into urban constructions has resulted in a flood of experimental and innovative methods aimed at net-zero carbon projects.

However, the implementation of net-zero carbon projects in the realm of urban development is fraught with complexities and challenges. Real estate developers, pivotal actors in urban transformation, often find it challenging to integrate sustainable practices within the constraints of economic viability and regulatory frameworks (Oluleye et al., 2021). This study explores how real estate developers can implement embodied carbon reduction strategies while also making sure their business case is still profitable. Avoiding focus on common but less effective approaches, like buying carbon credits to offset emissions. Instead, looking at efficient and realistic ways to reduce embodied carbon in real estate projects while making sure the business case remains profitable.

The aim is to guide real estate developers towards creating projects that are truly net-zero carbon and economically successful, helping build a future where our cities are more resilient against climate change and other challenges.

1.1 Problem statement

In recent years, the urgency to address climate change has been recognized at both global and national levels. The Paris Agreement, ratified by nearly 200 nations, underscores the global commitment to limiting the rise in worldwide temperatures to below 2°C, and ideally restricted to 1.5°C higher than pre-industrial levels (IPCC, 2019). Central to this objective is the transition to net zero carbon emissions, especially in sectors contributing significantly to the global carbon footprint, such as real estate development. In the real estate sector, there is much that can be done because the construction sector accounts for 40% of global greenhouse gas emissions (GHGs) (Dutch Green Building Council, 2021; Ahmed et al., 2022). Due to the growing population, energy consumption is expected to reach 53% in the next decade (Kumar et al., 2020), which will likely increase emissions. Thus, designing and constructing buildings with the least amount of negative environmental effect is the aim. There are two components for the lifecycle emissions of buildings: operational and embodied emissions. Since the operational emissions account for more CO2, a lot of work and research has gone toward lowering these emissions. But research has shown that embodied emissions in buildings are becoming more and more significant, even though lifecycle emission analysis often downplays their relevance (Ibn-Mohammed et al., 2013). Of the 40% of total CO_2 emissions, 29% are operational emissions, and 11% are material-related emissions (Dutch Green Building Council, 2021). According to the 2050 Paris Agreement goal, these figures have created a pressing need to significantly restructure the industry toward significant emission reductions in order to attain carbon neutrality by the middle of the century (Wimbadi et al., 2020). Achieving net zero carbon often requires offsetting the carbon somewhere. But

"More than 90% of rainforest carbon offsets by biggest certifier are worthless, analysis shows" (Greenfield, 2023). Greenfield (2023) shows that 94.9 million carbon credits are claimed by companies but there are 5.5 million real emission reductions done. According to DGBC, we should do our best to reduce emissions as much as possible. Using carbon offsetting, where we try to balance out our carbon dioxide emissions by investing in environmental projects, should be our last option. When we do have some emissions left, we need to carefully decide how much of these emissions we can offset (DGBC, 2021). These offsets aren't allowed to be counted in the overall carbon reduction targets, making sure projects meet the goals of the Paris Agreement. Because there's a risk that some companies might pretend to be carbon neutral just by buying offsets. This can be misleading because it makes it seem like the company has no emissions, which is not true in today's market (DGBC, 2021). The United Nations' Climate Change Panel (IPCC) also says that offsetting should only be used when there's absolutely no other way to reduce emissions.

Next to the sustainability goals the Netherlands also faces a housing shortage which is ever-rising. To tackle the housing shortage in the Netherlands an agreement has been made with the provinces to make sure the demand for 900.000 extra dwellings is met by 2030 (Ministerie van Algemene Zaken, 2022). This means that every year 128.000 dwellings need to be built to make sure that in the end this goal is achieved. In 2022 74.000 dwellings were built to help tackle the shortage, but this is still not enough to get rid of the housing shortage according to CBS (2023). On top of the demand for new dwellings, there are much more and stricter sustainability goals/regulations that bring various barriers to new developments.

Currently, it is challenging to produce net-zero carbon buildings due to multiple obstacles. Climate neutrality is achieved when GHG emissions are decreased or prevented, and the additional ones are paid with carbon offsets by long-term GHG capture projects (UNFCCC, 2021). In the Netherlands, the real estate sector is uniquely poised with its combination of historic structures and modern urban development, making the challenge both multifaceted and compelling. Compliance with legislation is of course necessary, but an accumulation of sustainability ambitions by governments is often considered undesirable, because it puts pressure on the financial viability of a business case (Verheul et al., 2019), especially in complex expensive inner-city developments with fragmented land ownership (Hobma et al., 2019). Research has found that economic drivers and barriers were believed to be the primary concern for delivering zero-carbon buildings (Pan et al., 2021)(Heffernan et al., 2015)(Singh et al., 2019)(Ohene et al., 2022). The fact that most research on carbon reduction and associated financial obstacles comes from the building or architectural fields is one of its limits. However, very little study has been done on the developers' viewpoint on remaining profitable while implementing reduction strategies. When research of this kind is done, it often falls short of providing adequate answers and is superficial (Ohene et al., 2022).

As they are in charge of developing infrastructures that will either increase or reduce the continuous carbon emissions for decades, real estate developers are essential to the shift to net-zero carbon buildings. Although many times the scientific and strategic road to net zero carbon projects is obvious, the practicality of implementing these steps sometimes conflicts with the financial worries that these companies have. The difficulty is thus in striking a balance between the current economic needs and the longer-term environmental requirements. The paradox of net-zero embodied carbon development and developer profitability must be balanced. This research gap is addressed by paradox theory, which highlights the underlying conflicts and contradictions found in corporate sustainability initiatives. Firms confront trade-off considerations in sustainability performance, according to Haffar and Searcy (2015), balancing resource limits and conflicting goals. This emphasizes the need to balance environmental responsibility and business prosperity. The paradoxical viewpoint on business sustainability, as investigated by Hahn et al. (2014), recognizes contradictions between various, but interdependent and contradictory, sustainability goals. This viewpoint is critical for real estate developers, who must balance the competing aims of carbon neutrality and profitability. The paradox of planning, engagement, effect, and performance in sustainable cities and communities highlights the complexities of these conflicts at both organizational and social levels (Greco & Long, 2022). Therefore, this study seeks to explore how real estate developers can manage these paradoxical demands, aiming to achieve net-zero embodied carbon developments without compromising their economic viability.

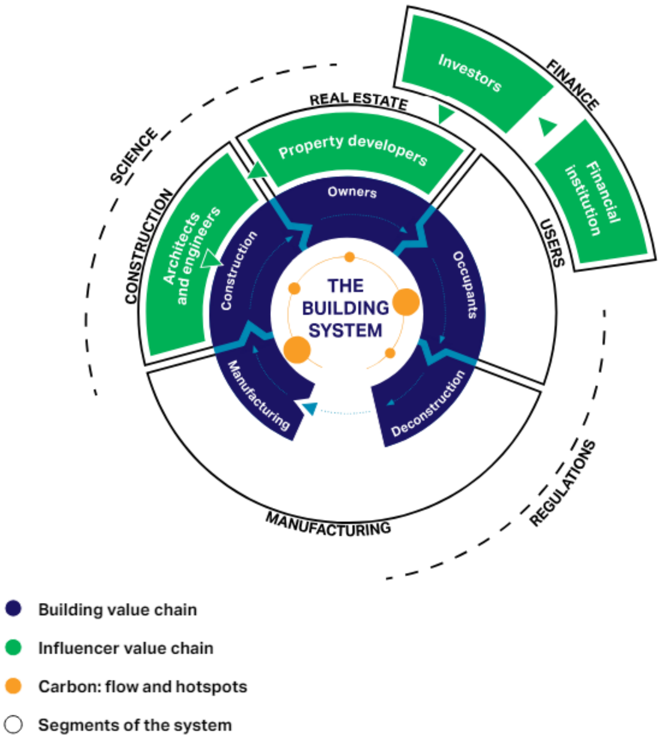

Figure 6: Carbon hotspots in the building system (LEVS, 2023)

The problem addressed in my thesis is the significant challenge real estate developers in the Netherlands face in constructing net-zero embodied carbon buildings while maintaining profitability, amidst stringent sustainability regulations, a national housing shortage, and the urgent need to reduce the sector's substantial contribution to global greenhouse gas emissions.

1.2 Scientific relevance

This research navigates the complexities of creating real estate projects that are both net-zero carbon and economically viable. The study is rich in interdisciplinary insights, drawing from urban development, environmental science, economics, and policy studies, making it a novel contribution to existing literature. It aims to improve current theoretical frameworks by exploring the balance between economic benefits and long-term sustainability. This involves a detailed study of the lifecycle of buildings, focusing on the often overlooked embodied carbon emissions. Ultimately, this study aspires to bridge the gap between the strategies to achieve net-zero carbon and their economic impacts, enriching the methodology and practical understanding of sustainable urban developments.

1.3 Societal relevance

Embracing net zero carbon targets in urban development carries significant societal benefits. It fosters cleaner and more sustainable environments, promoting healthier living conditions and numerous community health benefits. This alignment with sustainability enhances the economic resilience of the real estate sector, safeguarding it against market fluctuations and regulatory uncertainties. For instance, in the Netherlands, integrating sustainable practices helps in preserving the cultural and historical essence of places, while meeting contemporary challenges. This approach to development encourages stronger community relationships and attracts investors who prioritize sustainability. The findings of this study have the potential to influence and shape policies, steering society toward a future marked by sustainable urban living.

1.4 Research topic

Managing profitability with embodied carbon reduction is a key challenge in real estate management. While profitability focuses on financial gains, embodied carbon reduction considers activities' economic, social, and environmental impacts over an extended period. The main research question and sub-questions were formed to tackle this problem. A conceptual framework makes the relationships between the problems more visual.

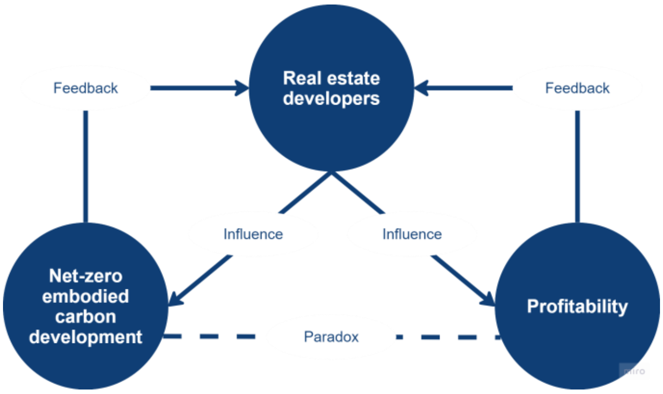

Figure 7: Conceptual framework (Own illustration)

As seen in the conceptual framework (figure 2) there is a paradox between net-zero embodied carbon development and profitability. Managing this paradox is the key to achieving profitable and net-zero carbon development for real estate developers in The Netherlands.

Thus the main research question is: **How can developers manage the paradox between profitability and embodied carbon reduction?**

The sub-questions that help answer the main research question are:

[SRQ1]: How can embodied carbon in real estate development be assessed?

[SRQ2]: Which regulations for embodied carbon in building projects are in place now and may be implemented in the future, and which ones could affect the decision-making of developers?

[SRQ3]: What strategies are currently available to developers to reduce embodied carbon in their projects and how are they used in practice?

[SRQ4]: How much does the consideration of reducing embodied carbon factor into the decision-making process of developers in present practice?

[SRQ5]: What modifications do developers make to the business case parameters to implement strategies aimed at reducing embodied carbon?

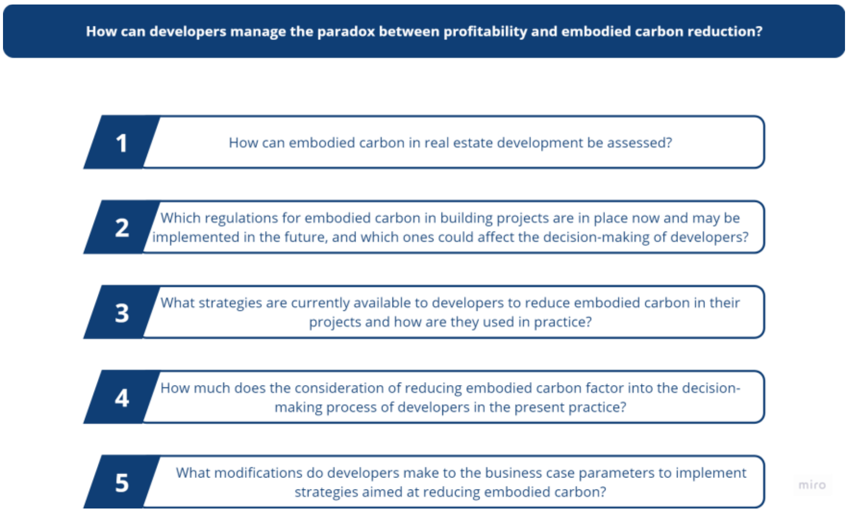

Figure 8: Sub-questions (Own illustration)

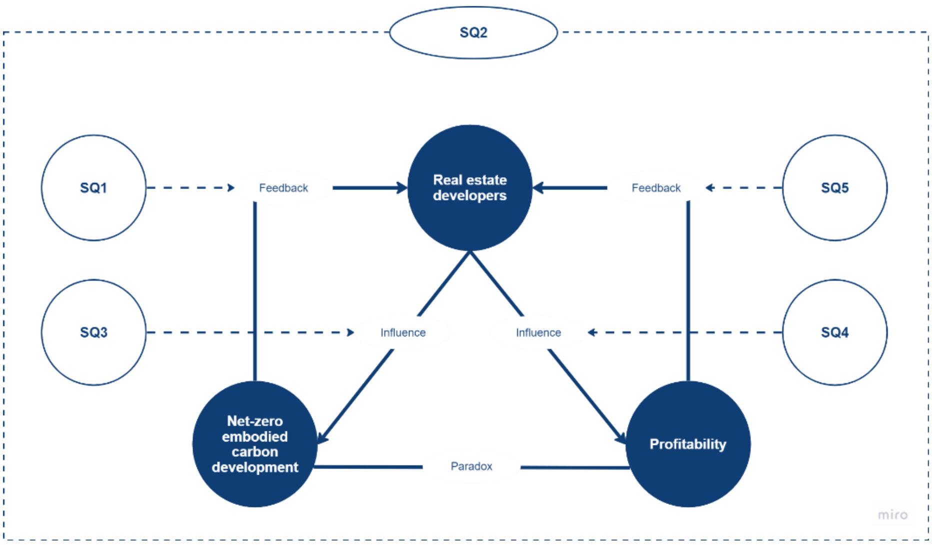

Figure 9: Sub-questions relationship with conceptual framework (Own illustration)

1.5 Goals and objectives

By 2050 all developments need to be carbon net-zero built. The main objective of this research is to help guide developers to strategize the right way when it comes to net zero carbon buildings. The developers need to make a profit while implementing embodied carbon reduction strategies. The goal is to assist developers in achieving net zero carbon targets without compromising profitability. Furthermore, researching the subject and trying to come up with something tangible that developers might be able to use in real life would be amazing in my opinion. So I would like to come up with something that developers can use during the process of their projects.

1.6 Dissemination and audiences

This research is mainly supposed for developers, but it can also be used by other stakeholders like municipalities or investors. The real estate developer is assisted in achieving net zero carbon targets without compromising profitability. The municipalities might gain from the policy adjustments recommended, that further enable developers to achieve both net-zero carbon and profitability goals. Real estate investors can also use the strategies to assist in achieving net-zero developments. Furthermore, the academic community can leverage the insights and data presented in this study to further the realm of knowledge in sustainable urban development.

1.7 Outline

The outline of this research is represented in figure 5, this is the outline of the research when it is completely done:

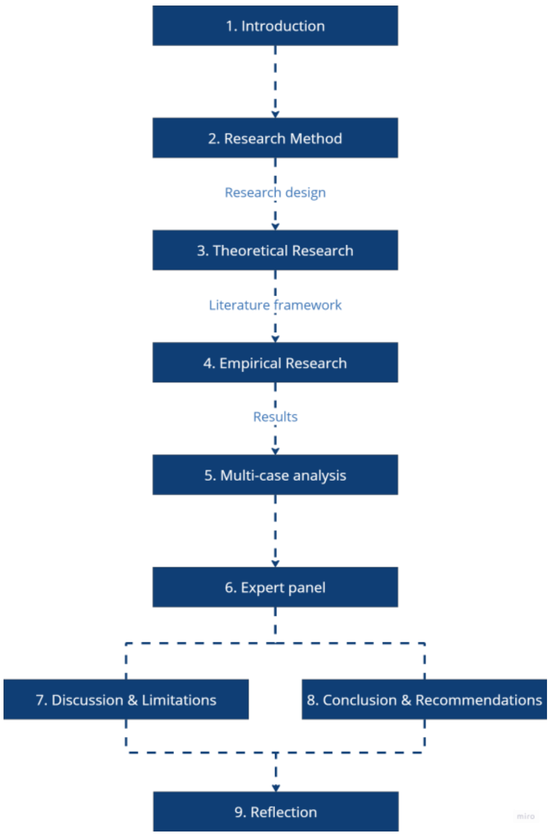

Figure 10: Research outline (own illustration)

Chapter 2

Research Method

2 Research method

This chapter outlines and provides justification for the research approach used in the study. It begins by explaining the sort of research, which helps create a basic comprehension of the research design. Subsequently, a comprehensive study of the research design is conducted, explaining the precise techniques used for both data gathering and analysis. The subsequent chapter delves into an examination of the data management plan, comprising techniques for data storage, retrieval, and analysis and ethical considerations. This detailed review offers a precise outline of the methodological approach that supports the investigation.

2.1 Research design

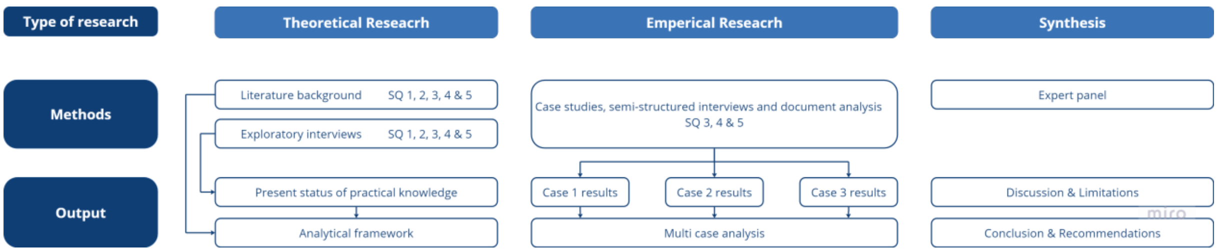

Figure 11: Research design (Own illustration)

Guided by the model presented by Saunders et al. (2019), which highlights an organized approach to research, this study is conducted. This approach, sometimes compared to an onion, emphasizes the need to comprehend and express each layer before advancing to the fundamental elements of data gathering and analysis. It promotes the need for a comprehensive understanding of the preliminary choices that facilitate the progression toward these pivotal phases of research. This study aims to examine how real estate developers might use embodied carbon reduction strategies to achieve net-zero carbon developments while ensuring financial viability. This analysis aims to clarify the seeming contradiction between attaining net-zero carbon goals and maintaining profitability. The primary objective is to thoroughly examine the complexities of decision-making processes related to net-zero carbon objectives, to provide developers with practical insights for implementing more effective embodied carbon reduction methods.

This study will use a blend of deductive and inductive approaches. A deductive technique is first adopted, in order to provide a strong theoretical foundation for the present theories about the financial implications of net-zero carbon in real estate development. In this phase, an analytical framework is developed by analyzing current literature and conducting exploratory interviews to collect evidence that either supports or contradicts these theoretical assertions. Subsequently, an inductive strategy will be used. This phase aims to reveal unique insights and patterns that arise from the case study data, enabling the creation of new ideas and approaches that improve understanding of how developers might have a successful business case while using embodied carbon reduction methods.

Figure 6 shows the research design. It illustrates how the objectives, applied research methodology, analytical framework, and (sub)questions relate to one another. To tackle the research topic and sub-questions, qualitative methodologies are employed in this study. Blaikie and Priest (2018) emphasize that qualitative methods specialize in producing detailed descriptions and uncovering the interpretations of social actors. Given the study's goals and the chosen theoretical approach, utilizing qualitative methods is particularly appropriate and effective for this research. This approach aligns with the study's objectives, enabling a comprehensive and nuanced exploration of the subject matter.

Theoretical research

Theoretical research is mainly used to answer both sub-question 1 *"How can embodied carbon in real estate development be assessed*?" and sub-question 2 *"Which regulations for embodied carbon in building projects are in place now and may be implemented in the future, and which ones could affect the decision-making of developers?"*. The theoretical research is done to define the main concepts of this study and to broaden the theoretical background. Because the subject is so new several government documents and websites are used next to the obvious Google Scholar and Scopus. Furthermore, Exploratory interviews are conducted to get a grip on the viability of the theory in practice. The theoretical research is built upon a comprehensive review of existing knowledge in the relevant fields. For tackling Sub-question 3 *"What strategies are currently available to developers to reduce embodied carbon in their projects and how are they used in practice?*", a framework is developed, drawing insights from a range of literary sources, and validated by interviews. In addition, to address Sub-question 4 *"How much does the consideration of reducing embodied carbon factor into the decision-making process of developers in the present practice?"*, a project timeline framework on the decision-making processes of developers was made, which is validated in the interviews. Furthermore, a thorough examination of diverse literature sources led to the identification and organization of key business case parameters, these are also validated by the interviews. These frameworks and models play a crucial role in the analysis of case studies and the formulation of interview questions. The culmination of this process was the establishment of a literature-based framework, which served as the cornerstone for answering sub-question 5 *"What modifications do developers make to the business case parameters in order to accurately represent the strategies aimed at reducing embodied carbon?"*. This framework led to the discovery of four principal themes: the concept of embodied carbon, regulations related to embodied carbon, the decision-making processes of developers, and the aspects of the business case. These themes are thoroughly explored in the theoretical research component.

Table 1: Theoretical research and exploratory interviews, sampling and data collection

Method	Amount	Sample	Selection criteria	Questions
Theoretical research	Depends	-	-	SQ 1 SQ 2 SQ 3 SQ 4 SQ 5
Exploratory interviews	3	Purposive sampling	1st interview: Company: commercial developer Sector: residential Expertise: embodied carbon reduction, profitability decision-making, and business case 2nd interview:	SQ 1 SQ 2 SQ 3 SQ 4 SQ 5

			Company: architect/carbon advisor Sector: residential Expertise: embodied carbon reduction strategies 3rd interview: Person: Head of a developer company Sector: residential Expertise: overall knowledge about the implementation of sustainability in project development and in a developers company.	

Empirical research

Sub-questions 3, 4 and 5 are answered by empirical research. The empirical research of this study primarily employs case studies and semi-structured interviews to get a more practical understanding of the central concepts. These methodologies are informed by preceding theoretical research, which delineates the foundational structure of the case studies and interviews. A case study is a kind of research technique where a single event or unit is thoroughly examined with the aim of better understanding developmental factors in relation to the environment. Applying contemporary theory to case study research as a framework that allows the analysis of potential deviations is the main focus. This methodology includes the comprehensive examination of a number of cases in addition to using a cross-case analysis to identify methods, enhance connection between variables, and formulate conclusions, hence increasing the research's validity. The contrasts and similarities across instances are examined using a multiple-case study approach, revealing insights into particular circumstances and across diverse contexts. The knowledge collected from the theoretical research and interviews may be evaluated using case studies.

The semi-structured interviews maintain a flexible question format, allowing the adaptation of queries in response to interviewee inputs. Such flexibility facilitates a more extensive exploration of topics, encouraging interviewees to share practical insights not extensively documented in existing research. The face-to-face interaction in the interviews is crucial, enabling the collection of genuine, immediate responses while providing a structured conversational environment for the interviewee. Given that sensitive information may be divulged during these discussions, a cautious and respectful approach to handling the disclosed information is imperative. Shenton (2004); "It is essential to uphold the trustworthiness of qualitative research through four fundamental pillars: credibility, transferability, dependability, and confirmability". These principles will guide the conduct and analytical rigor of the empirical research, ensuring a solid, ethical foundation and the reliability of the findings.

The objective of the empirical research is to address sub-question 3 *"What strategies are currently available to developers to reduce embodied carbon in their projects an how are they used in practice?"*. The architects and developers engaged in the case studies are interviewed using the framework indicated in the theoretical research. This method facilitated the identification and delineation of the reduction strategies used within them. Furthermore, sub-question 4 *"How much does the consideration of reducing embodied carbon factor into the decision-making process of developers in the present practice?"* and sub-question 5 *"What modifications do developers make to the business* *case parameters in order to accurately represent the strategies aimed at reducing embodied carbon?",* are answered. The approach starts with the definition of the overall decision-making process used by developers. The implementation of this approach in the case studies is then examined in order to look into any differences that may have occurred throughout the process of lowering embodied carbon. In the end, research will be done about the developers' current use of embodied carbon in their decision-making process. Additionally, a study was done to evaluate the effectiveness of the strategies to decrease embodied carbon on the business case after identifying the reduction techniques employed in the case studies.

Table 2: Theoretical research and exploratory interviews, sampling and data collection

Method	Amount	Sample	Selection criteria	Questions
Case studies	3	Purposive sampling	Implementation of embodied carbon reduction strategies Involvement of commercial developer An example for future net-zero developments	SQ 3 SQ 4 SQ 5
Semi-structured interviews	2 a 3 per case	Purposive sampling	Involved in the case Commercial developer Technical developer Architect	SQ 3 SQ 4 SQ 5
Document analysis	Depends		Useful documents from the cases Material list Certificates Business case Presentations	SQ 3 SQ 4 SQ 5

<u>Synthesis</u>

All findings of the previous sub-questions are used to create a comprehension between the theoretical research and the empirical research. A validation of the drawn conclusions are being tested by an expert panel. An expert panel is a gathering in which a group of specialists attempt to establish agreement on a certain issue via debate (Slocum-Bradley, 2003). This expert panel consists of four real estate developers who help test and define the framework for actual use in real practice.

Table 3: Theoretical research and exploratory interviews, sampling and data collection

Method	Amount	Sample	Selection criteria	Questions
Expert panel	1 panel 4 people	Purposive sampling	Commercial developers wanting to achieve net-zero carbon Knowledge about net-zero carbon Are not involved in de semi-structured interviews	-

To ensure active engagement in the expert panel and effective translation of comments into an actionable strategy, the panel will undergo recording and processing procedures similar to those used for interviews. The data obtained from literature, case studies, and interviews will be used and consolidated to examine and establish conclusion on how developers may implement embodied carbon strategies while maintaining profitability.

2.2 Data collection and analysis

During this research, a significant component involved a graduation internship at NEOO, a firm primarily engaged in real estate development within the Netherlands. NEOO specializes in the cultivation of sustainable, complex mixed-use development projects, predominantly within inner cities. Their operations, marked by a risk-assuming and autonomous nature, also extend to responsibilities undertaken on behalf of third parties.

NEOO possesses crucial expertise that is instrumental for this study, particularly in realms such as project development, with a focus on the conception of net-zero carbon developments, and project management, emphasizing the implementation of strategies essential for managing the challenges intrinsic to net-zero carbon construction. Their involvement has further been leveraged to identify suitable cases and provide purposive sampling for the different methods that enriches the research, facilitating direct engagement with pertinent stakeholders and experts within the field. Their guidance also plays a pivotal role throughout the research process, ensuring a well-directed and informed approach to the exploration and analysis undertaken in this study.

2.3 Data management plan

The software DMPonline from TU Delft is utilized for developing the data management plan (DMP) associated with this research. This DMP outlines the methodologies for data acquisition, record-keeping, and preservation throughout the study. Additionally, it details the approach for disseminating data post-research. Currently, the DMP is in its final form and is not subject to ongoing revisions. It is important to note that it highlights the potential involvement of sensitive data, so ensuring the confidentiality of this data is a top priority.

2.4 Ethical considerations

For this thesis, every participant in the research is approached for their voluntary participation, and informed consent is obtained prior to data collection. All volunteers are given detailed explanations of the study's objective and aims. Given that the research involves document analysis, strong safeguards are implemented to ensure their secure management. Furthermore, the usage of this information is completely anonymous. Throughout the research, the researcher retains an independent, ethical, and critical perspective. Despite the fact that the research is being carried out in collaboration with a graduation firm, it is critical to stress that the study's findings will be objective and uninfluenced by this affiliation. This study's ethical foundation is built on an unwavering commitment to objectivity and fairness.

Chapter 3

Theoretical Research

3 Theoretical research

This chapter examines the theoretical research on several themes, including embodied carbon, regulations related to embodied carbon, the decision-making processes of developers, and the aspects of the business case. The purpose of examining these four subjects is to answer sub-questions 1 and 2, and to provide a scientific basis for my study. Which results into the construction of an analytical framework that will be the basis for the empirical research.

3.1 Embodied carbon

3.1.1 Definition

Firstly net-zero carbon real estate development needs to be defined to understand embodied carbon. Net-zero carbon real estate development is a new concept that hasn't been thoroughly researched yet. This might be the result of different terminologies that roam the scientific world. But to come up with a definition for my research several literature are combined.

Lifecycle emissions resulting from the built environment consist of two components: operational and embodied emissions. Of the 40% of total CO2 emissions, 29% are operational emissions, and 11% are material-related emissions (Figure 7). According to the 2050 Paris Agreement goal, these figures have created a pressing need to significantly restructure the industry toward significant emission reductions in order to attain carbon neutrality by the middle of the century (Wimbadi et al., 2020).

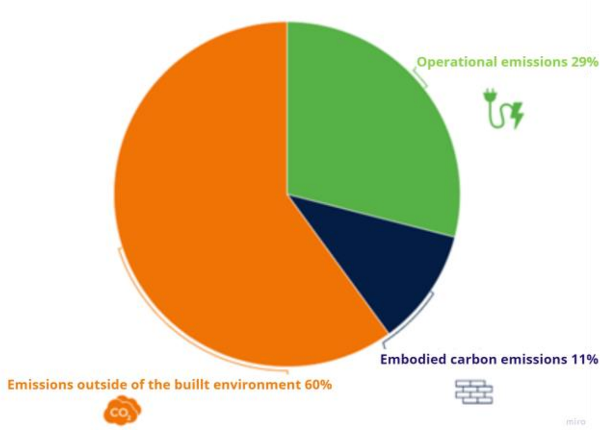

Figure 12: Percentages CO2-emissions of the building environment in the Netherlands (DGBC, 2021)

The terms virtually zero-energy building (NZEB), zero-energy building (ZEB), and net-zero energy building (NZEB) are the origins of the term "net-zero carbon building." The majority of these ideas deal with the building's operating energy use. "An efficient building with very little energy consumption that uses renewable energy sources, either on- or off-site, to meet its needs" (Grover, 2020), is the basic description of these ideas. The terms net-zero carbon building (NZCB) and zero carbon building (ZCB) have been around for a while. It is more difficult to provide an underlying standard description for these notions. Some associate it with structures that have no carbon emissions during operation, while others also take embedded carbon emissions into account (Grover, 2020).

"The possibility that building professionals will adhere to green building practices is decreased by ambiguity and imprecise vocabulary and meanings", claims Attia (2018). It causes erroneous construction and improper performance fluctuation due to conflicting interpretations. As a result, agreement on a common definition and its acceptance are necessary. particularly being aware of the fact that definitions and language for a notion increase in importance along with it. which thus raises the possibility of miscommunication (Attia, 2018).

The Dutch Green Building Council states that we ought to make every effort to minimize emissions. Our final resort should be carbon offsetting, which involves funding environmental projects to offset our carbon dioxide emissions. When there are still any emissions, we must carefully consider how much of them we can offset by adhering to established guidelines (DGBC, 2021). To ensure that projects satisfy the objectives of the Paris Agreement, these offsets are not permitted to be included in the total carbon reduction targets. Due to the possibility that some businesses may purchase offsets to claim to be carbon neutral. This may be deceptive as it implies that the firm has no emissions, which in the current market is untrue (DGBC, 2021). According to the IPCC of the United Nations, offsetting needs to be employed just in cases when there is no other viable means of reducing emissions.

In this study, the term "net-zero carbon real estate development" is defined as follows: A structure that achieves net zero operational carbon emissions and minimizes embodied carbon during its entire lifespan to align with the goal of attaining net zero at the worldwide or industry level in 1.5C scenarios. If all other options have been exhausted, any remaining emissions that cannot be eliminated should be counterbalanced by offsetting. (DGBC, 2021), (Ohene, 2022), (Pan & Pan, 2021), and (Ibn-Mohammed, 2013).

After defining net-zero carbon real estate development the embodied carbon definition can be defined. The carbon emissions that occur throughout the process of extracting material, logistics, production, development, maintenance, substitution, and end-of-life stages of a building's lifetime are referred to as embodied carbon (kgCO2e) (Keyhani et al., 2023). which is calculable using:

Material quantity (kg) x carbon factor (kgCO2e/kg) = embodied carbon (kgCO2e)

3.1.2 Carbon assessment

Embodied carbon, quantified in kilograms of CO2 equivalent (kgCO2e), includes the carbon emissions produced during the whole life cycle of a product or activity, from the extraction of raw materials to its disposal, including operations such as manufacture, transport, construction, destruction, demolition, and maintenance. When evaluating the effect of carbon emissions, it is crucial to clearly define the specific phases of the building's life cycle that are being taken into account. When discussing these phases in literature and reports, two main terms are often used.

The phrase 'life cycle embodied carbon' refers to the total amount of carbon emissions produced throughout the stages A1-A5, B1-B5, and C1-C4, as defined by the Institution of Structural Engineers in 2020. The emissions linked to Modules A1–A5 are expressly referred to as a building's completion in practice, which marks the point at which it is ready for occupancy and begins to emit operational carbon (Institution of Structural Engineers, 2020). It is an important construction milestone. Quantifying the carbon footprint up to this point is rather simple. Estimating the whole amount of carbon emissions associated with a building's entire lifetime is difficult due to the long duration of structures and the uncertainty surrounding their future use. It is worth mentioning that a substantial amount of carbon emissions is often generated until the project reaches practical completion (Rasmussen et al., 2018; Röck et al., 2020). As a result, efforts to reduce embodied carbon frequently prioritize the initial embodied carbon.

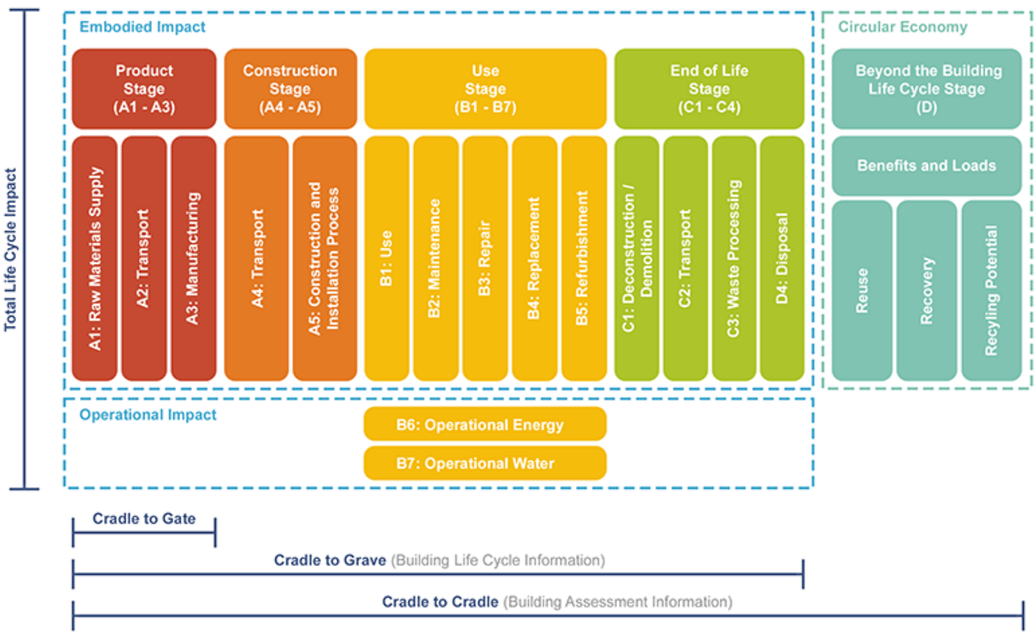

Figure 13: Life cycle stage for embodied carbon and operational carbon (Overbey, 2021)

The assessment of carbon emissions in the construction industry mostly relies on Life Cycle Assessment (LCA), a well-established and widely used approach (Amiri et al., 2021). Research by Ibn-Mohammed et al. (2013) and Pomponi et al. (2018) using Life Cycle Assessment (LCA) has emphasized the significant importance of embedded carbon throughout the whole lifespan of buildings. Even though LCA is acknowledged for its dependability and efficacy in analysis (Kayaçetin & Tanyer, 2018), it does present some difficulties. Performing Life Cycle Assessment (LCA) studies is a demanding procedure that needs substantial amounts of time and data (Häkkinen et al., 2015). The level of intricacy rises when the research includes a thorough examination of all phases and components of construction. In addition, the absence of sufficient data on material production and the environmental consequences of construction goods sometimes obstructs the ability to conduct thorough and accurate evaluations (Pomponi et al., 2018).

In the Netherlands, the environmental effect of materials used in construction is quantified and presented via the 'Milieuprestatie Gebouw' (MPG), which stands for the measurement of the environmental performance of a structure. The MPG, created by the Dutch government, provides a transparent and verifiable approach for assessing the environmental impact of building materials during their entire lifespan. The concept is condensed into a solitary numerical representation that signifies the expenses associated with shadows (Zizzo et al., 2017). The MPG mandate applies to all newly constructed residential and office buildings with a floor area above 100 m2 that are applying for building permits. The maximum allowable MPG is set at 1.0 for office buildings and a maximum for residential structures of 0.8. The intention is to progressively decrease this threshold, to reduce it by half by 2030. The environmental performance of a product, as shown in its Environmental Product Declaration (EPD), is essential for conducting Life Cycle Assessment (LCA) evaluations. EPDs, following International Organization for Standardization (ISO) regulations, serve as a means of worldwide communication about a product's environmental effects (Del Borghi, 2013). The papers undergo independent verification and registration, guaranteeing transparent and standardized data exchange (Institution of Structural Engineers, 2020). According to Harnot & George (2021), EPDs are considered the most reliable data source for evaluating the environmental effect of items. Manufacturers are increasingly publishing EPDs for building materials due to the increased need for transparency in sustainability claims (Zizzo et al., 2017; Röck et al., 2020). Nevertheless, the occurrence of EPDs is currently restricted, and in their absence, generic data may be included in LCA investigations. However, the World Economic Forum and JLL (2021) emphasize that this strategy requires thorough validation and honest reporting of data quality. EPDs also make it easier to use BREEAM and LEED systems to get credits under certification.

The use of a national database may enhance the quality of data (Kayaçetin & Tanyer, 2018). The Netherlands is home to the Nationale Milieu Database (NMD), which is a compulsory resource for calculating the environmental performance of buildings in permit applications. The NMD categorizes data into three distinct groups: manufacturer-specific data (Category 1), industry-group data that is not unique to any particular brand (Category 2), and generic, untested data that is also not specific to any particular brand (Category 3). According to all the exploratory interviews, the available data is insufficient to make an accurate assumption of the CO2 in projects. There is a need for a global scale database and tool with enough data to test projects on their CO2 emissions (Interview 1A, 2023)(Interview 1B, 2023)(Interview 1C, 2024).

In addition to the LCA technique, a range of methods are used to compute the carbon footprint of a building, serving both research and practical purposes. EC3 and Simapro, which are commonly used programs, provide user-friendly carbon footprint estimates for architects and engineers. However, the reliability and accuracy of these estimates rely on the extent and precision of the databases they use (Grover, 2020). Life cycle data is used by spreadsheet-based applications like "One-click LCA" and "GPR materials". Advanced levels of analysis use BIM-based systems like as BIMpact, which need comprehensive data on materials and environmental implications. Nevertheless, De Wolf et al. (2017) highlight that several of these tools exhibit a deficiency in transparency and may not be up-to-date.

3.1.3 Building layers

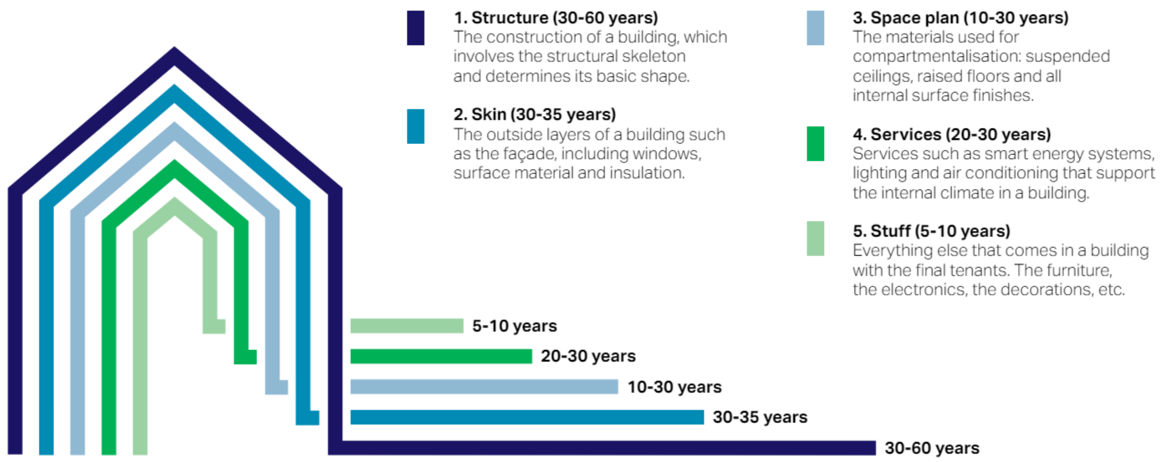

Figure 14: Building layers by Brand (1994) (Arup &wbcsd, 2023)

Understanding the different parts of a structure and the amount of embodied carbon produced by each part is essential. Brand's (1994) theory describes buildings as a combination of strata, which are called S-layers, that make up building compositions. This concept is based on the different projected durations of the building materials and components. The carbon impact of these architectural components is closely correlated with their projected lifespan. The five distinct levels suggested by Brand (1994) are illustrated in the figure above. Arup & wbcsd (2023) studied the embodied carbon emissions using Brand's S-layer structure in their study. Their research distinguished between the original embodied carbon [A1-A5] and that of the use and demolition phases [B1-C4], as seen in Figure 9. The results emphasize that at the beginning stage, the structural components are crucial. The attention moves to the services throughout the usage and demolition stages, thoroughly encompassing both structural elements and services.

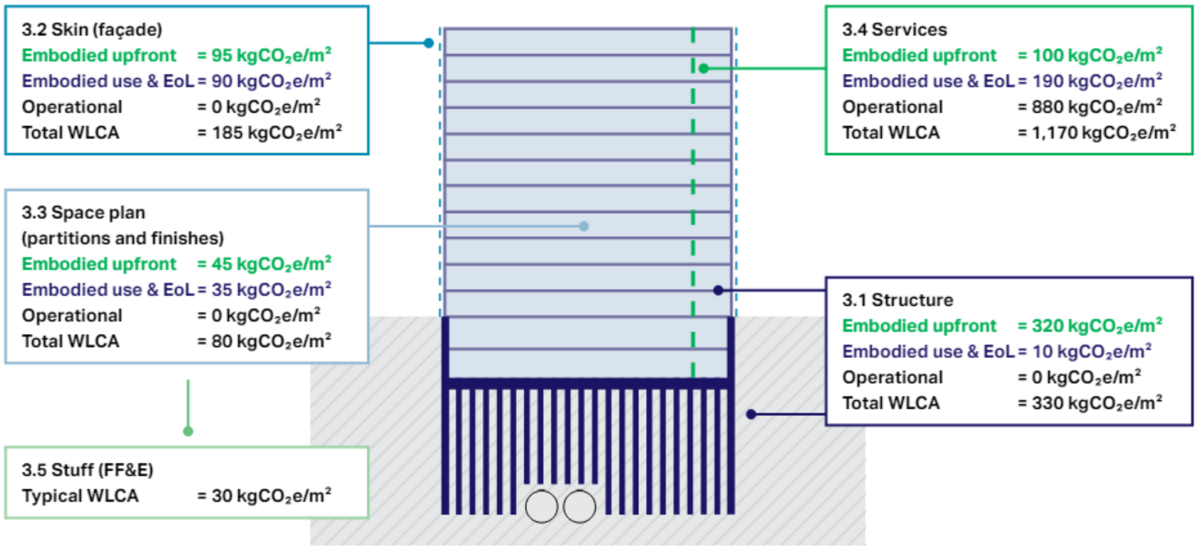

Figure 15: Embodied carbon emissions per building layer by Brand (1994) (Arup & wbcsd, 2023)

3.1.4 Carbon-offsetting

Sturgis (2017) emphasizes the intricate nature of modern building construction, acknowledging that even if there have been substantial reductions, some carbon emissions are unavoidable. Buildings get the "net-zero carbon" classification by offsetting these remaining emissions, so they cancel out their overall effect on atmospheric carbon levels. Carbon offsetting, an essential tool for neutralizing emissions, is of utmost importance in this context. According to Allen et al. (2021), carbon offsetting may be classified into two main categories: emission reductions and carbon removals. Emission reduction entails the implementation of tactics aimed at mitigating prospective emissions, such as replacing fossil fuel-dependent power plants with sustainable energy alternatives. Financial incentives are also used in theoretical ways to safeguard natural ecosystems. In contrast, carbon removal involves the direct extraction of carbon from the atmosphere via processes such as afforestation, soil carbon improvement, and the conversion of atmospheric carbon into stable forms, such as rocks, through demineralization.

At now, the majority of carbon offsets that are offered mostly consist of emission reduction. According to Allen et al. (2021), emission reduction alone is required but not enough to achieve long-term net-zero emissions. On the other hand, carbon removal provides the clear benefit of actively removing emissions from the environment. To maintain credibility and prevent allegations of "greenwashing," it is advisable to have third-party organizations, such as NGOs, supervise the acquisition of these superior offsets. As highlighted by the World Economic Forum & JLL (2021), these autonomous and non-governmental organizations have a crucial function in certifying and disseminating offset certificates.

Nevertheless, it is important to recognize that carbon offsetting is often subject to scrutiny over its efficacy and genuineness, due to apprehensions about deceptive activities (Greenfield, 2023), (Greenberg, 2021) & (Chapman, 2023). Consequently, this study takes the position that carbon offsetting should not be considered as the main approach for decreasing carbon emissions. This decision arises from the increasing doubt over the trustworthiness and real effectiveness of carbon offset programs, emphasizing the need for more straightforward and clear-cut approaches to reducing carbon emissions.

3.1.5 Targets

In order to create net-zero carbon buildings, it is imperative to set appropriate targets that can be offset. If not, any building might be declared "net-zero carbon" simply by offsetting all of its residual carbon emissions (as seen in 3.1.3). Fighting the symptoms will not solve the root cause of the issue, which is why achieving net-zero carbon on a global scale is imperative. Two approaches to determining these objectives have been investigated: one based on the 1,5C carbon budget and the other on actual practice.

Target based on current practice

Establishing a baseline for the typical business-as-usual embodied carbon figures might be useful to begin setting a target. Based on wbcsd & Arup (2023), there is currently no unanimity on what this average may be. The business-as-usual benchmark of 800 kgCO2e/m2 is determined by an informed assumption on the average upfront (A1-A5) figure in the same report. It is noteworthy to acknowledge that although the validation of this mean value is legitimate, it is predicated on life cycle assessments of edifices that have been computed with the owner's approval. If building owners and developers do not prioritize carbon reduction, it is possible that they will not conduct a life cycle assessment (LCA), leading to a higher real value. However, based on this standard and the knowledge that carbon emissions need to be cut in half by 2030, the wbcsd & Arup (2023) suggests that a target of 400 kgCO2e/m2 would be a good place to start.

Target based on 1,5-degree carbon budget

The Dutch Green Building Council (DGBC) adheres to a certain method in establishing their carbon emission goals, by the global warming threshold of 1.5 degrees outlined in the Paris Agreement. The DGBC's strategy differs from traditional approaches by being based on the fundamental notion of the global carbon budget, rather than building upon established practices. The use of this approach has resulted in the creation of a precise carbon allocation for the building industry in the Netherlands, limited to a maximum of 100 million metric tons (Mt). Following that, the DGBC has formulated precise benchmark values for carbon emissions per square meter for different categories of buildings. Currently, these standards are set at about 200 kg CO_2e/m^2, with a projected incremental tightening every three years, in pursuit of a reduction goal by 2050. Buildings that fulfill these criteria are qualified to get the 'Paris proof' accreditation from the DGBC.

Table 4: Paris proof limit values for new development (DGBC, 2021)

Paris Proof limit values	Embodied carbon kg CO2-eq per m2			
	2021	**2030**	**2040**	**2050**
Residence (single family)	200	126	75	45
Residence (multi family)	220	139	83	50
Office	250	158	94	56
Retail	260	164	98	59
Industry	240	151	91	54

Table 5: Paris proof limit values for renovation (DGBC, 2021)

Paris Proof limit values	Embodied carbon kg CO2-eq per m2			
	2021	**2030**	**2040**	**2050**
Residence (single-family)	100	63	38	23
Residence (multi-family)	100	63	38	23
Office	125	79	47	28
Retail	125	79	47	28
Industry	100	63	38	23

The DGBC's objectives are more strict than those established by the World Building Council for Sustainable Development (wbcsd), marking a significant difference in worldwide agreement on embodied carbon targets. In addition, the DGBC implements a lower barrier for renovation projects, recognizing the unique difficulties and opportunities in this industry. However, this distinction raises significant concerns about categorizing projects as either renovations or new developments, which necessitates a clear delineation to guarantee the efficient implementation of these goals. According to Interviewee 1A, the outcome varies based on the specific strategy and objective used. Several initiatives claim to be Paris Proof, however this assertion hinges on whether they have estimated their impact based on a global temperature rise of 2 degrees Celsius or 1.5 degrees Celsius. There is a need for a universally accepted approach and objective to achieve the Paris Proof (Interview 1A, 2024). The aims set by DGBC serve as the foundation for this study.

3.1.6 Carbon-pricing

Carbon pricing is a method used by both the commercial and governmental sectors to give a monetary value to carbon emissions, hence helping efforts to cut emissions and fulfill climate commitments (Carbon Pricing Leadership Coalition, 2018). As noticed by "Het Klimaatverbond Nederland" (2022), there is a significant difference in carbon pricing in the Netherlands, with varying prices allocated to a ton of carbon for various reasons. This variation shows that lower costs may be used deliberately to discourage high-impact climate behaviors, whilst higher prices may not affect some choices. The key to the successful execution of these several pricing levels is maintaining clarity about the goals and reasons behind each price.

Figure 16: EU carbon prices (Cornago, 2022)

Internally establishing a carbon price may greatly improve decision-making by exposing the hidden costs associated with various alternatives. On the contrary, estimating offsetting costs using a carbon price requires a more sophisticated methodology. This complexity stems in part from the linking of offsetting pricing with global and continental trade prices, which is impacted by the European Union's Emissions Trading System (ETS), a financial system aiming at reducing carbon emissions. The ETS works based on limited and diminishing emission rights that may be sold on the market (Gerlagh et al., 2022). Notably, carbon costs in the EU went through the roof, from over 20 €/tonne CO2 in 2019 to more than 90 €/tonne CO2 in 2022. Even though largely intended to major enterprises and national bodies, this pattern in the ETS market signals that the cost of carbon-intensive materials is about to climb. This rise is part of a larger trend, suggesting carbon is becoming a more significant component in economic values, notably in the voluntary carbon offset market.

Finally, the dynamics of carbon pricing, both in regulatory and voluntary settings, are fast shifting, reflecting the growing economic importance of carbon emissions in the larger framework of climate change mitigation initiatives. All the exploratory interviews mentioned that the carbon price most likely continue to rise which results in the market shift from traditional building methods to CO2 reduction methods (Interview 1A, 2023)(Interview 1B, 2023)(Interview 1C, 2024).

3.1.7 Embodied carbon reduction strategies

A variety of studies have investigated methods to reduce the embodied carbon in real estate projects. This body of research, as highlighted by Akbarnezhad & Xiao (2017) and Pomponi & Moncaster (2016), identifies five key strategies.

<u>1 – Low carbon materials</u>

Akbarnezhad & Xiao (2017) emphasize the need of using materials with a reduced carbon footprint in order to decrease embodied carbon in construction. Dimoudi & Tompa (2008) conducted research that emphasizes the significant role of concrete and steel, which are crucial structural components, in contributing to the total embodied carbon of a structure. These materials account for a percentage range of 59.57–66.73%. The carbon incorporated in construction materials may exhibit a variation of up to 40% based on the specific kinds of concrete and steel used. This underscores the need of exploring alternative building materials with lower carbon footprints. The use of low-carbon materials might result in a decrease in CO2 emissions of about 30% and 34.8% (Gonzalez & Navarro, 2006; Sham et al,. 2011). These studies have proposed various **biobased** materials, including lumber, hemp-lime composites, and bamboo as feasible alternatives. On a per-mass basis (kg CO2e per kilogram material), Figure 8 compares industrial emissions with the storage of CO2 of several materials. There is no functional equivalence between the uses of any material, hence this image should not be used to compare materials (Pomponi et al., 2020).

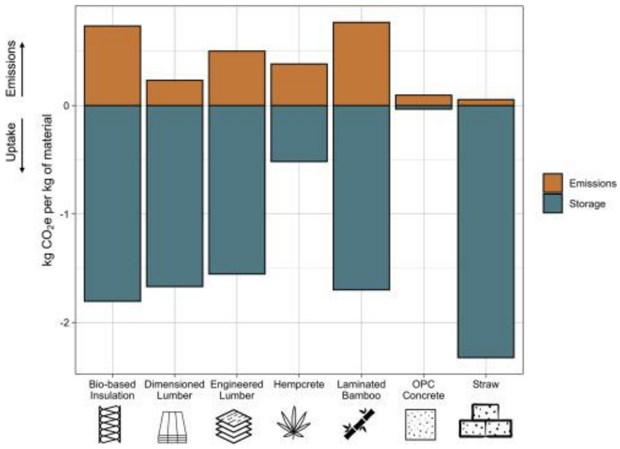

Figure 17: Net carbon-storage potential of building materials (Pomponi et al., 2020)

2 – Material minimization

Akbarnezhad & Xiao (2017) state that reducing material use is crucial for decreasing the embodied carbon in buildings. **Optimizing design** is the main approach to accomplish this decrease. Minimizing unnecessary design may significantly reduce the amount of materials used, resulting in a 10% drop in embodied carbon (Yeo & Gabba, 2011; Pomponi & Moncaster, 2016). Furthermore, Sobota et al. (2022) highlight the significance of the **compactness of a building** to material consumption. Compactness is the measure of a building's efficiency, calculated by comparing the size of its envelope to its practical floor space. The use of fewer materials for its exterior in relation to its useable area results in a more compact building. Sobota et al. (2022) also highlight that **prolonging the lifetime of service components** may help decrease CO2 emissions. Poon et al. (2004) also observe that the **waste produced** in the production- and construction-phase has an impact on the amount of materials utilized in the project.

3 – Material reuse and recycling

Akbarnezhad & Xiao (2017) emphasize the need of including recycling and reuse procedures in the choice of materials. **Recycling** is advantageous because it alternates ecologically harmful production processes with more eco-friendly secondary manufacturing, hence decreasing emissions. According to Wiik et al. (2018), this method also aids in the preservation of finite resources, reduction of waste, and restriction of land use. Moreover, the practice of **reusing materials** and components, particularly in the context of building restorations or destruction, has a substantial impact on reducing the amount of carbon emissions associated with the production of these materials (Akbarnezhad & Xiao, 2017). Many components of a structure often retain their functionality even beyond the building's lifespan. These may be reused for analogous or disparate purposes. Materials with a large amount of embodied carbon are particularly crucial for reuse, since replacing them with new materials might result in substantial environmental benefits (Tingley et al., 2018) . Figure 7 demonstrates the specific phases of the Life Cycle Assessment when recycling or reuse may be used.

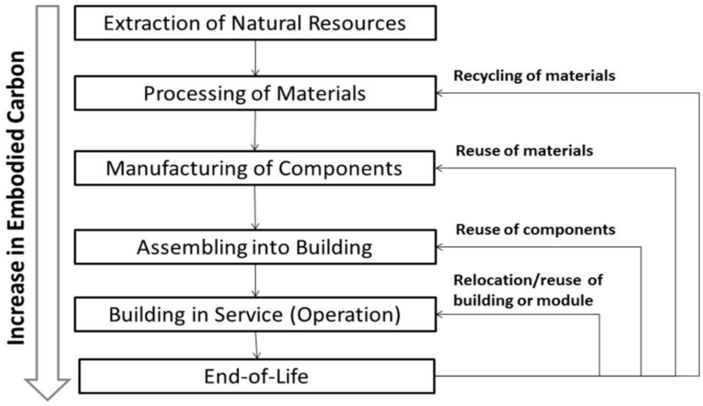

Figure 18: Increase in embodied carbon of a structure as it moves through different stages of its life cycle (Akbarnezhad & Xiao, 2017)

<u>4 – Local sourcing of materials and components</u>

Akbarnezhad & Xiao (2017) provide a comprehensive analysis showing that transportation plays a substantial role in the amount of embodied carbon found in buildings. Different components within the transportation sector contribute to the attainment of a structure with reduced carbon emissions. **Key determinants impacting transportation** emissions include the quantity of items moved, their size, the distance traveled, and the mode of delivery used. According to Pomponi & Moncaster (2016), **using materials that are supplied locally** may significantly reduce the negative effects caused by transportation. Additionally, while aiming to develop low-carbon structures, it is essential to take into account significant transportation emission variables, including the quantity of transportation journeys needed, the mode of transportation used, and the length of travel.

<u>5 – Construction optimization strategies</u>

Efficiently optimizing construction operations is a vital strategy to reduce the amount of embodied carbon associated with building projects. Akbarnezhad & Xiao (2017) highlight the need to reduce emissions associated with construction, which are attributed to the use of temporary building materials and machinery. Various approaches may be used to reduce embodied carbon during construction. These operations include the **optimization of construction processes** to limit equipment downtime, selection of the most **efficient equipment** for particular jobs, improvement of the use of machinery, and reduction of on-site mobility in both directions. Furthermore, according to Pomponi & Moncaster (2016), the process of construction optimization may be improved by using **advanced construction equipment** and reducing the duration of the project. In addition, Pomponi & Moncaster

(2016) state that using prefab-components and **off-site production procedures** is an efficient method for further decreasing embodied carbon.

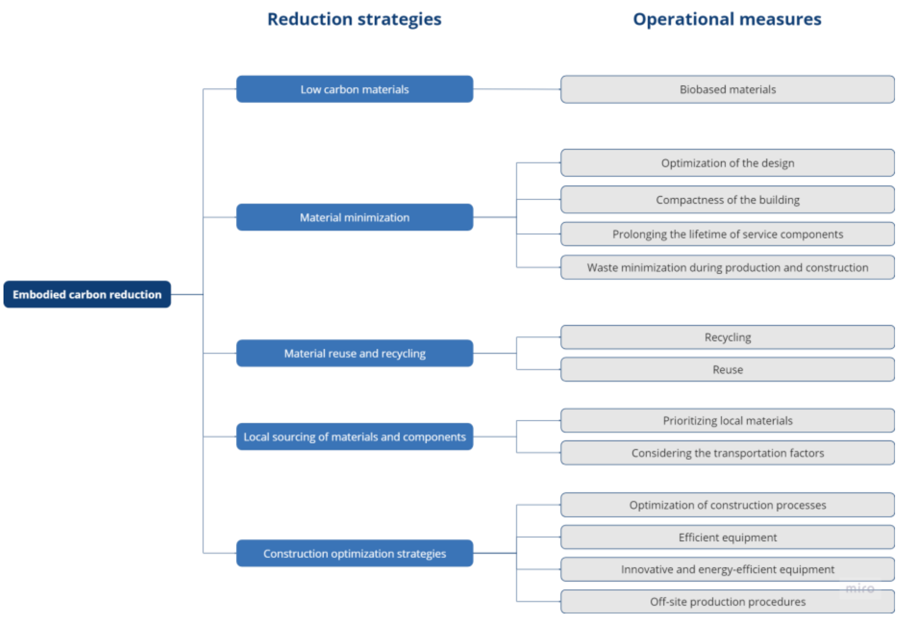

Figure 19: Embodied carbon reduction strategies and its operational measures summary (Own illustration)

When striving for sustainable building, it is important to recognize the significant impact of making little, gradual improvements. Although there is a temptation to support a complete transition to entirely biobased building, the present trends in the sector suggest that these methods are still limited to a small specialized market. Most building projects often adhere to set standards, frequently neglecting more environmentally friendly measures. Nevertheless, a practical strategy indicates that it is more beneficial to make little improvements in the sustainability of a greater number of buildings rather than making big progress in a smaller group (Interview 1C, 2024). Currently, as we move towards the widespread use of lumber as a main building material, it is essential to achieve measurable reductions in carbon dioxide emissions via other approaches. Simultaneously adopting a variety of eco-friendly techniques may be challenging and difficult, sometimes causing development to stop. Thus, it is crucial to prioritize the exploration and implementation of hybrid solutions. These stepping stones provide a gradual and controllable shift from traditional building methods to ones that actively contribute to the reduction of CO2. Implementing a staged strategy not only helps to make the transition easier, but also guarantees that the industry as a whole progresses towards the overarching objective of sustainability (LEVS Carbon Based Design, 2023).

3.2 Regulations related to embodied carbon

This chapter provides an analysis of regulatory frameworks, with a special focus on the environmental requirements established by the European Union and the Netherlands. The discussion primarily centers on the concept of embodied carbon.

As previously said, COP21 represented a noteworthy achievement by making firm promises to reduce carbon emissions. At the end of 2019, the European Commission initiated the 'European Green Deal,' an all-encompassing policy designed to address the issue of climate change. An essential aspect of this project is the ambitious objective to reduce carbon emissions in Europe with 55% by 2030 against the levels recorded in 1990. To do this, the 'fit for 55' package has received significant support from European and national legislative authorities, providing a legal need to comply with this objective as outlined in the European Climate Law (IPCC, 2019; DGBC, 2022).

Furthermore, the European Commission implemented into the 'European Green Deal' the 'Circular Economy Action Plan'. The EU plan entails a firm commitment to attaining climate neutrality and zero net emissions by 2050. It includes 35 distinct goals, a few of which pertain to EU sustainable product regulations. The goals include the implementation of novel rules within the construction and building sector, with the specific purpose of achieving significant reductions in emissions. The main initiatives include implementing sustainability standards for construction materials, improving recycling practices, advocating for longer product lifespans, implementing digital logbooks for buildings, integrating Life Cycle Assessment (LCA) in public procurement, and establishing a sustainable financial framework within the European Union (Dutch Green Building Council, 2022).

The European Commission has emphasized the need to invest more in environmentally friendly companies and goods in view of the growing consequences of climate change and the depletion of resources. It acknowledges the financial sector's pivotal role in the transition to sustainable practices, in line with the goals of the European Green Deal. In response, a comprehensive plan has been implemented that includes measures such as the establishment of a taxonomy for sustainable activities within the European Union and the requirement, under the Corporate Sustainability Reporting Directive (CSRD), that corporations disclose data on a range of environmental, social and governance (ESG) metrics. Ensuring business openness about their environmental and social sustainability policies, risks, and results is the goal of the CSRD. In turn, this gives stakeholders and customers the knowledge they need to make informed choices and have an impact on these companies' sustainable business practices.

The Energy Performance of Buildings Directive IV (EPBD IV) was passed by the European Parliament on February 9th, 2023. This marks the prospective implementation of more stringent carbon emission limits (European Parliament, 2023). This regulation stipulates that all newly constructed buildings must achieve full operational carbon neutrality by 2028, while public structures are expected to meet this criterion by 2026. Moreover, the order mandates the incorporation of solar technology in all newly constructed buildings by 2028. Significantly, this is the first occurrence in which the European Parliament has underscored the need to consider CO2 equivalents across the whole lifecycle of a building. Starting on January 1, 2027, it will be mandatory to calculate the Global Warming Potential (GWP) for structures that are greater than 2,000 square meters. This need will then extend to all new projects from January 1, 2030. Furthermore, there are anticipated reduction goals to be implemented after 2030 (European Parliament, 2023).

Currently, there is no explicit rule in the Netherlands regarding the permissible amount of embodied carbon dioxide equivalent (CO2-eq) emissions per square meter. Starting from July 1, 2021, the Dutch government mandates the inclusion of an Environmental Performance Building (Milieuprestatie Gebouw) calculation for new building projects (RVO, 2021). According to the Renewable Volume Obligation (RVO) for the year 2023, the "Milieuprestatie Gebouw" (MPG) has become the main method for evaluating the environmental consequences of a structure. It is a crucial measure of sustainability and provides insight into the environmental effect of a building's materials during its entire lifespan. Greater sustainability is accomplished by using biobased materials, resulting in a reduction in MPG values. It is a requirement for all building permit applications for new residential or office projects that exceed 100 m² in size, to calculate the MPG. It stipulates that residential buildings must achieve a maximum MPG score of 0.8, while business buildings must achieve a maximum MPG score of 1.0. The government intends to progressively reduce this stipulation to an MPG of 0.5 by 2030, with ongoing deliberations to expedite this objective to 2025 (RVO, 2021). Nevertheless, it is crucial to acknowledge that the MPG rating does not just reflect the amount of carbon dioxide emitted, since it also includes other types of emissions. This approach makes it unclear how much CO2 is emitted exactly per square metre, which hinders effective monitoring and awareness. As PPm directly links to CO2 emissions per m2, it provides a more precise and relevant perspective when trying to reduce embodied carbon in a building project. The MPG score varies depending on the factors included or excluded in the computation. For instance, some projects include PV-panels or subtract the accumulated CO2, while others do not. There is no universally accepted criterion for the MPG score. (Interview 1C, 2024).

Municipalities possess a variety of alternatives to implement sustainable practices. Local governments have the authority to establish sustainability criteria for new buildings as part of their zoning plans. Nevertheless, some demands are not deemed lawful. At the end of 2020, the ‘North Netherlands District Court’ determined that municipalities are not permitted to impose sustainable construction criteria using contractual mechanisms, namely through private law. Section 2(5) of the 'Woningwet' states that the 'Bouwbesluit' is limited to specifying building norms that mainly focus on safety, health, usability, energy efficiency, and environmental factors (Catch legal, 2021). This ruling expanded the understanding of the term 'environment' in this particular circumstance. The court's reasoning was based on the interpretation that sustainable construction rules are included by the term 'environment', as deduced from Section 7a of the Housing Act.

In the current regulations, there is a strict division between operational and material-related emissions. On the one hand it is mandatory to do a BENG calculation for the operational emissions and energy and on the other hand it is mandatory to do a MPG calculation for the embodied emissions. Having a good score on one of them can mean a worse score on the other (W/E adviseurs, 2021). So, there is a need to make integrated considerations to arrive at the most efficient solutions. Focusing solely on (operational) energy-neutral buildings can have a negative impact on embodied emissions now, and vice versa (Interview 1C, 2024).

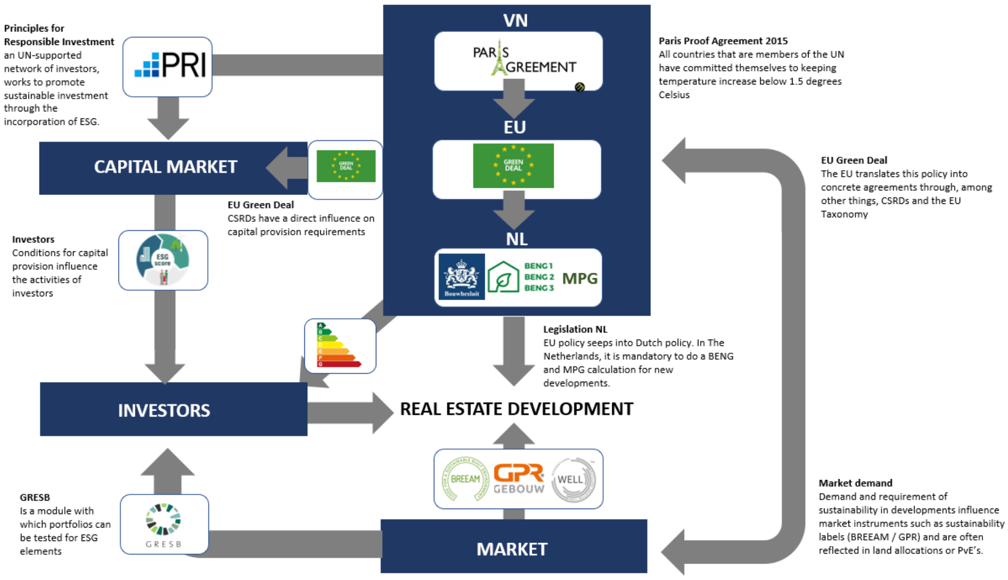

Figure 20: Regulation scheme related to sustainability goals (Own illustration)

3.3 Decision-making process of developers

One of the biggest problems today is the creation of more practical working definitions for developers, as not all developers are created equal. According to Boanada-Fuchs (2022), the expression "developer" refers to a broad spectrum of entities, encompassing both small businesses and large international organizations. With an emphasis on creating high-quality integrated communities, turning a respectable return, and reducing financial risks, developers tend to focus on relatively short-term, project-based development (Heurkens, 2019).

This study focuses mainly on medium- to large-scale residential building complexes developed by real estate developers. It might be claimed that the complexity of large constructions makes it more difficult to build net-zero carbon structures than in less complicated developments. According to Pomponi et al. (2018) a tall building's design is also common in developments because of the extensive material amounts and the infrastructural needs surrounding projects.

All developers have to deal with risk, especially when it comes to financial performance and commercial strategy (Boanada-Fuchs, 2022). As per the official discourse, developers are entitled to a specified payment for the effort and risk they face. Still, it's unclear how risk and profits are connected (Boanada-Fuchs, 2022).

Real estate investment entails allocating resources for extended durations, aiming to offset expenses and generate significant returns. The capacity to make good judgments is crucial in this process, as it allows for optimizing returns and reducing risks. Inadequate decision-making may result in financial losses. The choices are based on a thorough examination of the project, with a major emphasis on risk assessment owing to uncertainties in cost recovery and profit creation (Virlics, 2013).

Within the domain of real estate investing, the primary determination is on selecting which assets to purchase or cultivate. This is the process of predicting future results, usually presented in a business scenario (Atherton et al., 2008). Crucial factors in this procedure, rental revenue, costs to operate, and returns are essential to inform decision-making. However, it is not possible to control or predict all of these factors with absolute precision. The influence of market-driven elements, such as risk, return, and rent, restricts the level of control in real estate investment. This adds complexity to the investment process since the results are very sensitive to changes in these input variables (Atheron et al., 2008). A thorough examination of these topics using a business case model is elaborated in Subchapter 3.4, entitled "Business case."

In addition to financial factors, decision-making is also influenced by non-financial variables such as sustainability (Warren-Myers, 2012; Mantogiannis & Katsigiannis, 2020). Sustainability comprises the elements of the environment, society, and economy (Dobrovolskienė et al., 2021). Jackson & Orr (2021) state that it also plays a crucial role in several 'Environmental, Social, and Governance' (ESG) guidelines. This study largely focuses on environmental sustainability, specifically examining requirements such as attaining a fuel efficiency rating of 0.5 miles per gallon (MPG), which is further elaborated upon in Subchapter 3.2 titled "Regulations related to embodied carbon."

The process of the transformation of an abstract concept into a physical asset might require many years. To efficiently navigate this, the process of real estate development is divided into several stages. After each step, a thorough assessment of the project is carried out to ascertain the feasibility of making further expenditures (Gehner, 2003). These crucial occasions are referred to as decision-making moments for investments, indicating the beginning of a phase and acting as intersections between various phases of growth (Gehner, 2008). As stated by Schmidt and Calantone (2002), these moments are referred to as 'project review points' and serve as junctures when choices are made on whether to continue or terminate the project. Choosing to terminate a project signifies the developer's lack of confidence in its successful conclusion, leading to the implementation of an exit plan. On the other hand, choosing to go forward demonstrates the developer's dedication to finish the project and all the expenditures with it. Figure 11 shows a comprehensive framework that delineates the many stages and steps involved in the process of real estate development.

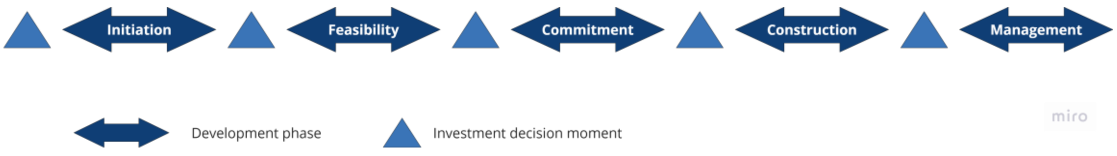

Figure 21: Stages of development and occasions of investment decisions (Based on Gehner, 2008)

The decision activities described by Gehner (2008) and Willows et al. (2003) are used as the basis for defining investment decision-making activities. They are cross-referenced to come up with the investment decision-making activities described in Table 6. These will be tested and validated by the exploratory interviews.

Table 6: Investment decision-making activities (Based on Gehner, 2008 and Willows & Conell, 2003)

Gehner (2008)	Willows et al. (2003)	Investment decision-making activities:
1. Recognition	1. Identify problem and objectives	**1. Recognize and identify**
2. Determination of decision criteria	2. Establish decision-making criteria	**2. Establish decision-making criteria**
3. Search for information	3. Assess risk, identify options and appraise options	**3. Search for information**
4. Identification and analysis of courses of action	4. Make decision	**4. Identify options and assess risk**
5. Evaluation	5. Implement decision	**5. Make a decision and implement it**
6. Authorisation	6. Monitor and reassess	**6. Monitor and reassess the decision**

3.4 Business case

The real estate calculation process takes place within the individual phases of the property real estate process (land development, project development, real estate exploitation and use), but especially at the transition points, the phases within the process in which transactions are prepared and concluded (the land operator sells land to the developer who develops real estate that he may sell to an investor sells). The method is complicated because land and property extraction are handled separately. This is mostly because of the active role of local governments in spatial growth. A Discounted Cash Flow (DCF) method is usually used by land operators to figure out how much the land is worth, as stated by Bosse et al. (2008). Then, the developers on the project figure out if the price of the land is fair compared to how much it will cost to build and how much it might sell for. This way, they can make a good return. The main thing for investors or users to do is figure out the "Internal Rate of Return" (IRR). This is a moving way to figure out an investment's time-adjusted net return by looking at its income and costs

(Meijer, 2011). Furthermore, as Bettini et al. (2016) indicate, the precision in calculating construction costs cannot be understated. Accurate cost estimation is a critical success factor in real estate, influencing both feasibility and financial stability (Bettini et al., 2016). In Table 6, a list of the factors that affect real estate developers' business cases can be seen:

Table 7: Business case parameters from the literature

Business case parameters		
Costs	**Income**	**Deal summary**
Gross m2 BVO	Lettable m2	Total project costs
Ratio	Income €/m2 (year)	Total investment value
Amount of units	Indexation	Profit
Construction costs	Income (/year) after index	Profit on costs
Additional costs	VAT	Profit on investment value
Land costs	Yield	Return of equity
Indexation	Value	Internal rate of return
Equity		
Loan		
Interest		
Contingency		

The way sustainability affects the financial side of real estate has changed a lot over time. At first, people who work in the real estate business thought that sustainability wouldn't have much of an effect on rents and returns. This view has changed, especially in the U.S., where sustainability is now seen as important for managing risk, increasing profits, and getting ahead in Responsible Property Investment (RPI), as Pivo (2008) points out. Sustainable buildings have better rental rates, lower running costs, and slower rates of depreciation and regulatory decline, all of which are good for the bottom line. These benefits can make more people want to buy and might even lower the price risk premium (Pivo, 2008). According to Apanaviciene (2015), using resources efficiently, lowering your carbon footprint, and following eco-friendly building practices not only help protect the environment but also raise the property's long-term value by lowering costs and attracting tenants and investors who care about the environment. Studies by Eichholtz et al. (2010) and Pivo (2008) found that green-rated homes in the U.S. had capital value rises of 6% to 16%. In the same way, buildings that use less energy tend to have higher rents because they have many benefits, such as lower costs and better names. Fuerst and de Wetering (2015) have shown that buildings that have a BREEAM certificate get higher prices than non-certificated buildings. According to Leskinen et al. (2020), green certification raises sales prices, rental income, and usage rates. However, it can lower returns, which are called risks. Ellison et al. (2007) say that sustainability is seen as a way to lower obsolescence, decline rates, and capital expenditures to lower risk. Eichholtz et al. (2010) say that buyers are often interested in sustainable properties because they have lower running costs, better company image, and lower risks. After all, the buildings last longer.

According to LEVS book Carbon based Design (2023), in order to meet the 2023 criteria outlined in the Paris Agreement, an additional investment of 2-3% of the overall construction cost would be required to update the present design. This little increase is a wise decision considering the rising costs of products with large carbon footprints, assuring that the extra charge will become less significant over time. Investing in this not only shows a smart use of resources but also creates future possibilities by safeguarding a piece of the carbon budget. The demand for sustainably designed houses is increasing among buyers due to the availability of green mortgages and the rising number of individuals who prioritize and are prepared to pay more for environmental sustainability. Banks are now acknowledging the significance of funding sustainable homes and adjusting their lending procedures to support broader sustainable investment objectives. This makes owning a greenhouse more accessible and attractive to a larger audience. Currently, biobased alternatives come with a higher price tag, but this scenario is expected to shift as the cost of conventional materials climbs (see Figure 17). Additionally, the expansion of biobased production capabilities and the increasing market appreciation for sustainable construction practices will further drive this change (Interview 1C, 2024).

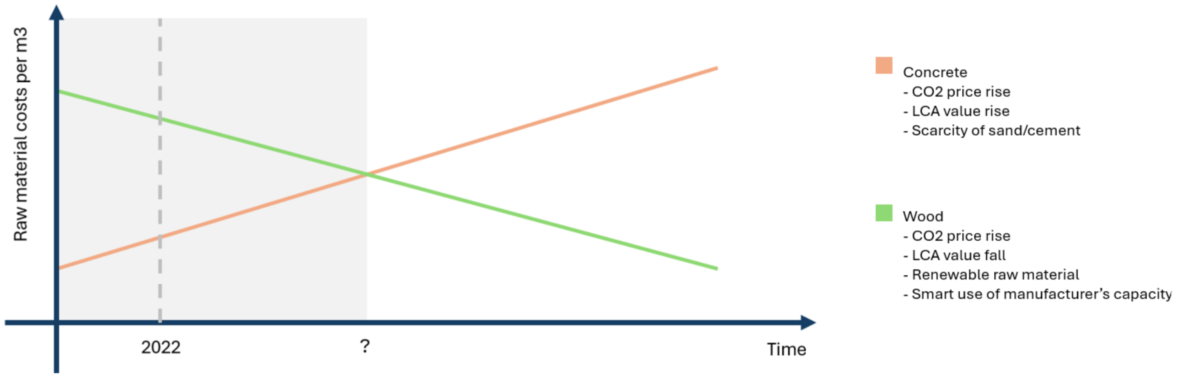

Figure 22: Expected change in material costs per m3 (Own illustration based on LEVS Carbon based Design, 2023)

Although these ideas are helpful, there is still not a lot of research that looks into how sustainability affects real estate decisions. Newer buildings usually meet higher standards for sustainability, but older buildings may need a lot of work to make them more energy efficient. This is called the "brown discount" (GBCA, 2007). To figure out how sustainability affects real estate prices, you need to look at things like capital costs, lifespan, final value, and discount rates. Green standards might require big financial investments, which could lower the value of homes. In any case, the idea of less danger could make sustainable products more valuable (GBCA, 2007).

3.5 Analytical framework

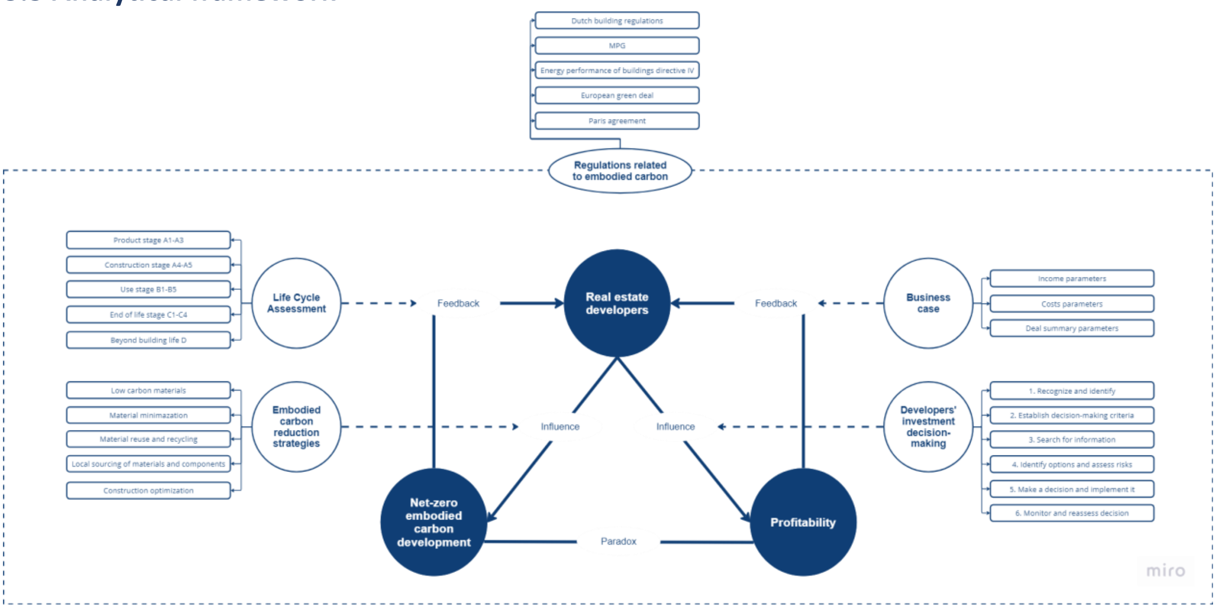

Figure 23: Analytical framework (Own illustration)

Chapter 4

Empirical Research

4 Empirical Research

The findings from three case studies: Populus, SAWA, and Koelmalaan are presented in this chapter, addressing sub-question 3 *"What strategies are currently available to developers to reduce embodied carbon in their projects and how are they used in practice?"*, sub-question 4 ***"****How much does the consideration of reducing embodied carbon factor into the decision-making process of developers in present practice?"*, and lastly sub-question 5 ***"****What modifications do developers make to the business case parameters to implement strategies aimed at reducing embodied carbon?".*

The project's narrative, emission-reduction tactics, and an overview of the developers' decision-making process are all included in the intended scope. It also looks at whether the embodied carbon reduction affects operations and how decisions are made. The business case variables used are then analyzed, along with how solutions for reducing embodied carbon impact these variables in the selected cases.

The selection criteria for these cases are:

- The cases have implemented several embodied carbon reduction strategies and show the indicators of such strategies, to make sure the found strategies in theory are examined in present practice.
- They are residential developments because in this thesis the focus is on this real estate sector. This is because every sector has different embodied carbon targets so to focus on all sectors would be too broad, that's why it was chosen to focus on residential buildings so the cases can be specified and the Netherlands can keep its focus on tackling the housing shortage.
- The cases must have different developers and architects to get as many different eyes on the same problem we try to solve. This is chosen to prevent having the same answers in the interviews and to get as many experts and different views that can be examined.
- The phase of which the project is currently must be as recent as possible with still enough information available about what strategies they used, so the information isn't outdated.
- And there needs to be a sufficient amount of data for each case, so there is enough data to make a cross-case analysis of the three cases.

Figure 24: Location of the cases used (Own illustration)

4.1 Case Populus:

4.1.1 Case description

Figure 25: Render of project Populus from LEVS Architects (LEVS, 2024)

Populus is a project that is located next to the Romeynshof metro station in the Ommoord neighborhood of Rotterdam, blending people, nature, and urban life. The design includes four terrace structures situated inside a blue-green, somewhat raised landscape. Constructed from wood, this housing project consists of 210 apartments and is considered a pioneering example of wooden residential construction. Populus integrates a diverse cultural and socio-economic agenda with sustainable, cost-effective housing in an ecological pathway (Populus, n.d.).

Populus rejuvenates the region by providing a social uplift. A new central plaza is introduced, serving as a meeting point for many community activities. Populus focuses on the notion of Third Places, which are areas where individuals socialize and spend time apart from their homes and workplaces. The design integrates various areas including a physiotherapy clinic, library, performance area, and neighborhood café to create a feeling of safety and community involvement by strategically considering sightlines, light, openness, and intimacy surrounding the square (Populus n.d.). The size of the project is 25,900 m² GFA, of which 18,200 m² residential function consisting of 210 wooden rental and owner-occupied homes with collective (outdoor) spaces, 1,900 m² social (theatre, community center and library), 2,500 m² healthcare (GPs, pharmacy, physio and ERGO), 130m2 City Hall room, 3,050m2 of built parking and bicycle shed and semi-public green roof landscape (Populus n.d.).

The construction is constructed entirely from wood, with bio-based internal walls and insulation, resting on a high concrete foundation. Populus's CO_2 footprint, calculated using the Paris Proof material-bound technique by DGBC and NIBE, is already below the future objective of 50kg CO_2/m² GFA. This aligns with the Dutch Green Building Council's 2050 aim for the Paris climate goals. Timber beams from existing structures are also reused in the V-columns (Interview 2CB, 2024).

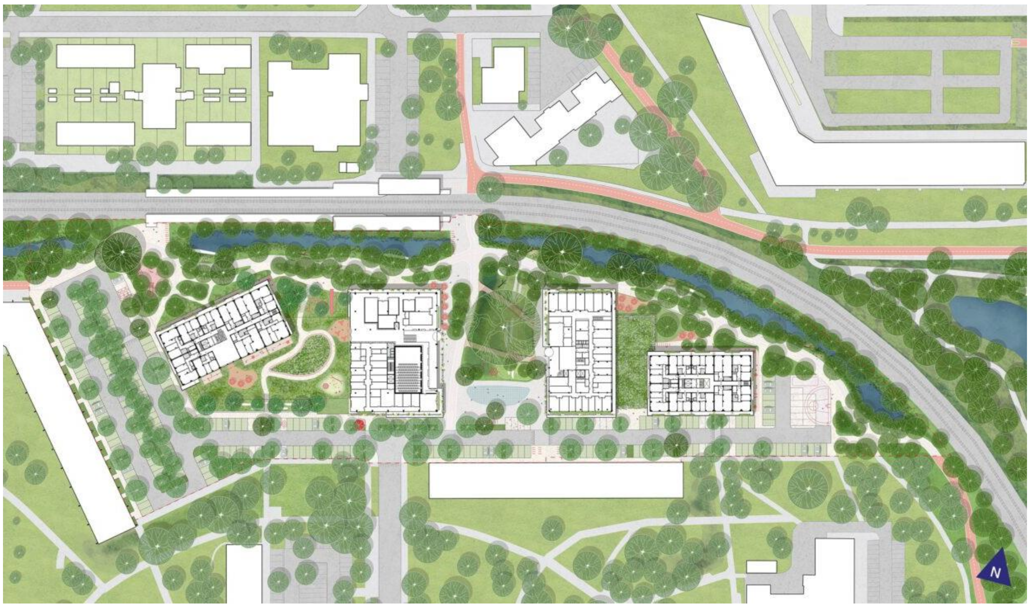

Figure 26: Plan of project Populus from LEVS Architects (LEVS, 2024)

The name Populus refers to both a giant poplar tree in the new central plaza and the new residents, guests, and people passing through Romeynshof. Romeynshof is conveniently located near a metro station, serving as a central point for public transportation, residential areas, workplaces, and recreational activities. It is intricately linked to the main ecological park structure and provides access to the Rotte landscape park. The four buildings are deliberately positioned to improve connectedness with the surroundings, concentrating public activity around a square and park, while a residential area is situated on the outskirts of the park (Interview 2CB, 2024).

The landscape design links Ommoord's primary park layout by expanding an ecological, aquatic area into the heart of Populus. It enables the nurturing of authentic, wild nature, inspired by Louis Le Roy's ideology. The terraces facing this ecological zone elevate the vegetation in the park, improving the area's three-dimensional aspect and encouraging a human-centered, nature-integrated lifestyle in a lush urban setting. The water structure, landscape, and terraces are used for collecting rainfall, improving biodiversity, and providing cooling (Populus n.d.)(Interview 2CB, 2024).

Figure 27: Render projected in the area of project Populus from LEVS Architects (LEVS, 2024)

Table 8: General information Populus (Own work)

Specification	Populus
Location	Rotterdam
Size GFA	25.900 m2
Design	2021
Construction time	-
Project delivery	Expected 2026
Developer	AM
Architect	LEVS Architecten
Contractor	BAM Wonen
Advisors	Includi, ZieglerGautier, Merosch, Mobycon, BAM Advies & Engineering, LOLA Landscape Architects, Vivid Vision
MPG score	0,56 €/m2 GFA
Amount of embodied CO2 per m2	<50 kg/m2

The developer

AM is a focused area developer that prioritizes social concerns in their building strategy. They create and design exciting and environmentally-friendly living spaces that have a beneficial influence on individuals, the environment, and society. AM, a subsidiary of the Royal Bam Group, is responsible for ensuring both the spatial quality and the quality of life. The Royal BAM Group, which is publicly traded on the Euronext Amsterdam stock market, has the objective of constructing a future that is environmentally responsible and capable of being maintained over the long term (Interview 2CA, 2024). They are enhancing their goods and services to expand their growth, consistently incorporating more digital solutions, matching with market trends, and increasing their sustainability. The project is funded by AM's own capital, showcasing AM's commitment to investing in pioneering and environmentally-friendly initiatives such as Populus.

4.1.2 Used embodied carbon reduction strategies

The following table shows a summary of the reduction strategies that were used in Populus. This information was gathered by doing interviews with the architect and developer involved in this project.

Table 9: Used embodied carbon reduction strategies in Populus (Interviews + document analysis)

Strategies	Measures	Application
Low-carbon materials	Biobased materials	Cross laminated timber (CLT) and laminated timber, are used for the core structure. FAAY retention walls. Usage of biocomposite facade materials and lightweight structural materials (Nabasco) that symbolize concrete but are from a biobased material, to reduce the carbon footprint.
Material minimization	Optimization of the design	They changed from 3D modular to a 2D prefab method. The 2D flat pack approach enhances flexibility in design and allows for customization in a way that fully prefabricated 3D modules may not. This can result in more efficient use of

		materials and can optimize the space according to the project's needs. They use a dual-layer parking system to reduce concrete usage and optimize the design.
	Compactness of the building	-
	Prolonging the lifetime of service components	-
	Waste minimization during production and construction	Because of the prefab method there is minimal waste production.
Material reuse and recycling	Reuse	They use urban mining, reusing materials from existing buildings or infrastructure within the new construction to reduce the need for new materials and lower the overall carbon footprint. existing materials from the site or nearby structures are assessed for their potential reuse within the new building. By using urban mining they want to see if they can get the MIA subsidy.
	Recycling	-
Local sourcing of materials	Prioritizing local materials	-
	Considering the transportation factors	-
Construction optimization	Optimization of construction processes	-
	Efficient equipment	-
	Innovative and energy-efficient equipment	-
	Off-site production procedures	2D prefab slabs are used for most of the project. flat pack construction involves creating flat elements (like panels for floors, walls, and ceilings) that are prefabricated off-site but are assembled on-site to create the three-dimensional structure.

= no impact = positive impact

4.1.3 The decision-making of the developer

This table shows the decision-making process of the developer in general. Furthermore, it shows the project-specific process it went through and how the incorporation of embodied carbon reduction changed the decision-making. The yellow color means the incorporation of embodied carbon reduction has a moderate impact on the decision-making process, the red color has a negative impact, and the green has a positive impact.

Table 10: Decision-making of AM (Interview + document analysis)

Steps	Developer general	Project-specific changes when incorporating embodied carbon
1. Recognize and identify	The identification of projects differs every time. So there is not one strategy they use at this step.	The project was acquired through a tender from the municipality.
2. Establish decision-making criteria	AM has established complicated decision-making because of all the different sectors that all have their own opinion. Overall they want to steer towards a sustainable built environment.	For this project, the criteria included not just CO_2 reduction but also enhancing circularity and supporting local biodiversity and inclusivity. The project team had higher criteria than the municipality set during the tender.
3. Search for information	The search for information is very project-specific, so there is no standard strategy.	The search for information was more challenging for this project than projects in a traditional way. They needed a lot of advisors and time to figure everything out.
		The information that was found can now be used for all their future projects. For them, it is an investment in future projects. They are part of the Royal BAM Group which can all profit from the information of this project.
4. Identify options and assess risk	For every project, there is an assessment done to review all the challenges and opportunities of the projects. Advisors can help to make sure all aspects are analyzed and risk is minimized.	Willing to accept modified returns on investment by prioritizing sustainability goals and embracing new construction methods like flat pack 2D elements despite potential unknowns and financial risks. One big risk was the influence of the vibrations of the metro on the lightweight structures.
		After facing these challenges ones the next time it will be more doable. They are investing in the risks right now so they don't have to do it in their next projects.
5. Make a decision and implement it	The investment decision is made by the investment team of AM and because they are part of the Royal BAM	A firm decision was made early in the planning phase to prioritize CO_2 reduction strategies, accepting that this would lead to less flexibility in design changes later on.

	Group they incorporate their strategies.	
6. Monitor and reassess the decision	The project is constantly monitored and reassessed to manage the risks.	There's a heightened focus on monitoring due to the innovative nature of the project and the need to manage risks associated with new construction techniques and materials.
		When building with embodied carbon reduction becomes more standard there is no need to do more thorough reassessments.

= moderate impact   = negative impact   = positive impact

4.1.4 Used business case parameters

The table below shows which business case parameters AM used to assess Populus.

Table 11: Used business case parameters for Populus (Interviews + document analysis)

Used business case parameters		
Costs	**Income**	**Deal summary**
Gross m2 BVO	Lettable m2	Total project costs
Ratio	Income €/m2 (year)	Total investment value
Amount of units	Indexation	Profit
Construction costs	Income (/year) after index	Profit on costs
Additional costs	VAT	Profit on investment value
Land costs	Yield	Return of equity
Indexation	Value	Internal rate of return
Equity	Subsidies	
Loan	Carbon credits	
Interest		
Contingency		

= added parameters

4.1.5 Impact of the embodied carbon reduction strategies on the business case parameters

This table shows the embodied carbon reduction strategies that were used in Populus and what kind of impact they had on the business case.

Table 12: Impact of the reduction strategies on the business case parameters of Populus (Interviews + document analysis)

Reduction strategy used	Explanation used measure	Impact on business case	Explanation of the impact
Low carbon materials	Cross-laminated timber (CLT) and laminated timber. FAAY retention walls. Biocomposite façade (Nabasco).	Construction costs	**Construction costs:** The price of the materials is higher than traditional materials.
		Additional costs	**Additional costs:** More expertise was needed so the additional costs were higher.
		Income €/m2 (year)	**Income €/m2 (year):** They expect the rent to be at the top of the market.
		Carbon credits	**Carbon credits:** The stored CO2 can be sold, but the amount is not yet specified.
Material minimization	2D flat pack approach enhances flexibility in design and allows for customization in a way that fully prefabricated 3D modules may not. Dual layer parking system.	Lettable m2	**Lettable m2:** The structure and use of 2D flat pack approach have a positive impact on the GBO/BVO ratio.
		Construction costs	**Construction costs:** The dual-layer parking results in the use of less material and construction effort.
		Additional costs	**Additional costs:** A lot more knowledge was needed to optimize the design accordingly.
	Prefabrication results in the minimization of waste and material.	Construction costs	**Construction costs**: The prefabrication results in less costs for the construction, due to less material and less time.
Material reuse and recycling	Urban mining	Subsidies	**Subsidies:** Because of the use of reusable and recycling material they probably get the MIA subsidy
Local sourcing of materials	-	-	-
Construction optimization	2D prefab components are mostly used for the project.	Value	**Value:** the construction time is lower which results in a higher value because the income comes sooner.
		Construction costs	**Construction costs:** The contractor had to bring in a lot more knowledge which resulted in higher costs.

■ = negative impact ■ = positive impact

4.2 Case SAWA

4.2.1 Case description

Figure 28: Render of project SAWA (MEI Acrhitects)

SAWA is Rotterdam's innovative tall building that is made out of timber, it reaches a height of 50m. Originally it focused on designing a cutting-edge, environmentally friendly timber housing complex to improve the local community and the city as a whole. SAWA offers a combination of 39 houses for sale, 20 homes for private lease, and 50 homes for mid-range rent (€700 - €1,000), as well as a restaurant and a community center. The homes are planned to be modern and roomy, each with its own outside space. The project includes community places specifically meant to foster amicable interactions among neighbors (Mei Architects, 2023)(Interview, 2AA, 2024). The developers proposed a plan to the Rotterdam municipal government aimed at reducing CO2 emissions, achieving national and international environmental goals, and offering affordable housing. After a series of conversations between the municipal authorities and the developer, the site was promptly allotted for development.

SAWA was designed with an emphasis on four key elements: decreasing CO2 emissions, offering affordable mid-rent housing, promoting biodiversity, and establishing shared communal spaces. A deliberate choice was taken to considerably reduce CO2 emissions in line with the goals of the Paris Proof Agreements, the European Green Deal, and Rotterdam's municipal environmental aims. The objective led to the construction of a building mostly supported by a cross-laminated timber (CLT) framework, significantly decreasing the reliance on concrete. Using CLT and other sustainable methods helps the building reduce its carbon footprint and actively collect carbon (Mei Architects, 2023). SAWA's building process effectively sequesters about 5,000 tons of CO2. The design process continually focused on minimizing embodied carbon.

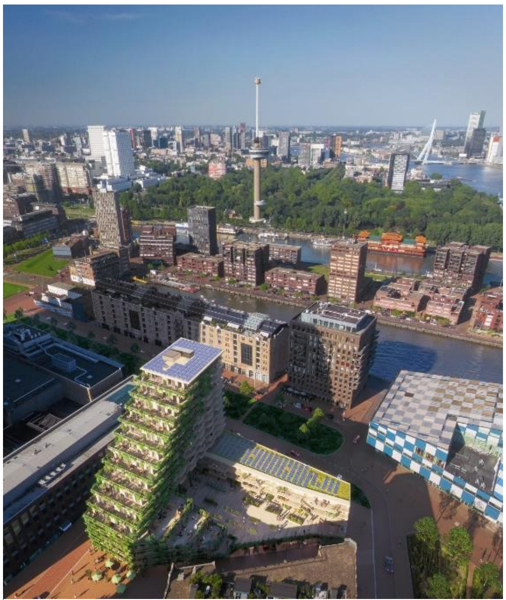

Figure 29: SAWA render projected in the area (MEI Architects

Table 13: General information of project SAWA

Specification	SAWA
Location	Rotterdam
Size GFA	12.000 m2
Design	2019
Construction time	In 2 years
Project delivery	Now in construction, delivery expected end of 2024
Developer	NICE Developers
Architect	Mei Architects
Contractor	ERA Contour
Advisors	Pieters Bouwtechniek, DGMR, Peutz, Adviesbureau Hamerlinck, Maatwerk in Bouwadvies, Aldus Bouwinnovatie, Pirmin Jung, Copijn, Bureau Stadsnatuur & Piet Vollaard, Duoplan, Studio Faber
MPG score	0,60 €/m2 GFA
Amount of embodied CO2 per m2	-

The developer

NICE Developers specializes in constructing using wood to create vibrant and sustainable communities. Mark and Robert are the two founders of NICE, with the investor Focus on Impact as a co-shareholder, making NICE part of a wider business collaboration. NICE is actively involved in wood building development on properties owned by Focus on Impact. NICE may create additional initiatives on a risk basis and perhaps invest with Focus on Impact on other locations via this relationship (NICE Developers, 2024). SAWA is their only project at the moment, but they are doing several tenders to acquire more projects to grow their business. (Interview 2AA, 2024)

4.2.2 Used embodied carbon reduction strategies

The following table shows a summary of the reduction strategies that were used in SAWA. This information was gathered by doing document analysis and interviews with the architect and developer involved in this project.

Table 14: Used embodied carbon reduction strategies in SAWA (Interviews + document analysis)

Strategies	Measures	Application
Low-carbon materials	Biobased materials	For project SAWA 90% of the core structure is made of cross-laminated timber (CLT) and laminated timber, with wooden components such as internal cavity walls and frames making up the other half of the facade's finish. The original concept called for building everything out of wood, however, this strategy turned out to be 20% more expensive than expected, making it unfeasible from an economic standpoint.
Material minimization	Optimization of the design	Because of the chosen column structure, the design is designed for an optimal GBO/BVO ratio and the use of less material. The galleries

		further enhance this efficiency because they don't count in this ratio. The implementation of ventilation type C, which involves natural supply and mechanical exhaust regulated by CO2, resulted in a substantial reduction in the need for ventilation ducts by 60 to 70%. This method enables the use of just diminutive, condensed fans. Furthermore, the installations are specifically intended to be easily removable and conveniently placed, which allows for simpler replacement and improves the overall efficiency of maintenance.
	Compactness of the building	-
	Prolonging the lifetime of service components	-
	Waste minimization during production and construction	-
Material reuse and recycling	Reuse	Instead of concrete for the dry ballast on the CLT floors, recycled gravel from local roofs is used. This also contributes to making the building circular, as the use of this gravel means the wooden structure is not attached to concrete but can be completely separated and reused if the project ever needs to be dismantled.
	Recycling	-
Local sourcing of materials	Prioritizing local materials	There is some local sourcing evident in the materials, particularly the wood used for the CLT, which is sourced from near the German border. The recycled gravel for the dry ballast comes from local roofs all around the country.
	Considering the transportation factors	-
Construction optimization	Optimization of construction processes	There is a degree of optimization shown. Noting how the nature of the materials utilized results in less noise and less heavy equipment.
	Efficient equipment	-
	Innovative and energy-efficient equipment	-
	Off-site production procedures	2D prefab components make up the primary supporting structure and the facade finishing, which resulted in saved time.

☐ = no impact ☐ = positive impact

4.2.3 The decision-making of the developer

This table shows the decision-making process of the developer in general. Furthermore, it shows the project-specific process it went through and how the incorporation of embodied carbon reduction changed the decision-making. The yellow color means the incorporation of embodied carbon reduction has a moderate impact on the decision-making process, the red color has a negative impact, and the green has a positive impact.

Table 15: Decision-making of NICE developers (Interviews + document analysis)

Steps	Developer general	Project-specific changes when incorporating embodied carbon
1. Recognize and identify	The identification of projects differs every time. So there is not one strategy they use at this step.	The project was acquired from the municipality of Rotterdam. From now on they will only go for projects/tenders that have CO2 reduction goals. To set an example that building with embodied carbon reduction is feasible.
2. Establish decision-making criteria	The developer set several decision-making criteria, they specifically want to deliver projects that have a positive impact on the built environment.	The municipality had lower sustainability goals for this project than the architect and developer came up with for this project. This is because they wanted to change the built environment with this project and put their names on the map. The decision-making criteria are expected to change every project because more information is available.
3. Search for information	The search for information is very project-specific, so there is no standard strategy.	The search for information was more challenging for this project than projects in a traditional way. They needed a lot of advisors and time to figure everything out. The information that was found for project SAWA can now be used for all their future projects.
4. Identify options and assess risk	For every project, there is an assessment done to review all the challenges and opportunities of the projects. Advisors can be broad in to make sure all the aspects are analyzed.	They are willing to modify their anticipated returns for "SAWA" that emphasize not just the amount of carbon contained but also value adding, biodiversity, circularity, and inclusiveness. During the examination of SAWA, certain risks were detected, such as fire safety issues related to the building, the availability and upkeep of wood, and uncertainties the time it takes. This modification is being made in anticipation of forthcoming investments in projects that prioritize comparable tactics for reducing CO2 emissions. Reflecting a long-term strategic approach to decision-making.
5. Make a decision and implement it	The decision is made by weighing every aspect that is analyzed against the criteria that are set. The decision is always made by the founders of the company.	The decision to build the project with CO2 reduction strategies was made in the initial phase of the project. When this decision is made there is no turning back, which results in less flexibility in the design in further phases.

6. Monitor and reassess the decision	The project is constantly monitored and reassessed to manage the risks.	Due to the impression of higher risks, the first stages of the project may be subject to more rigorous reassessments in terms of the embodied carbon.
		When building with embodied carbon reduction becomes more standard there is no need to do more thorough reassessments. SAWA had no objections from the local community because they implemented participation, suggesting a positive impact on the decision-making process by reducing external project risks.

= moderate impact = negative impact = positive impact

4.2.4 Used business case parameters

The table below shows which business case parameters NICE Developers used to assess their project SAWA.

Table 16: Used business case parameters for SAWA (Interviews + document analysis)

Used business case parameters		
Costs	**Income**	**Deal summary**
Gross m2 BVO	Lettable m2	Total project costs
Ratio	Income €/m2 (year)	Total investment value
Amount of units	Indexation	Profit
Construction costs	Income (/year) after index	Profit on costs
Additional costs	VAT	Profit on investment value
Land costs	Yield	Return of equity
Indexation	Value	Internal rate of return
Equity	Carbon credits	
Loan		
Interest		
Contingency		

= added parameters

4.2.5 Impact of the embodied carbon reduction strategies on the business case parameters

This table shows the embodied carbon reduction strategies that were used in SAWA and what kind of impact they had on the business case.

Table 17: Impact of the reduction strategies on the business case of SAWA (Interviews + document analysis)

Reduction strategy used	Explanation used measure	Impact on business case	Explanation of the impact
Low carbon materials	90% of the core structure is made of cross-laminated timber (CLT) and laminated timber, with wooden components such as internal cavity walls and frames making up the other half of the facade's finish.	Construction costs	**Construction costs:** The price of the materials is higher than traditional materials.
		Additional costs	**Additional costs:** More expertise was needed so the additional costs were higher.
		Income €/m2 (year)	**Income €/m2 (year):** The rent is at the top of the market at this location.
		Interest	**Interest:** The interest is positively influenced by green financing.
		Carbon credits	**Carbon credits:** The stored CO2 can be sold for approximately 400.000 euro.
Material minimization	Column structure and use of galleries	Lettable m2	**Lettable m2:** The structure and use of galleries have a positive impact on the GBO/BVO ratio.
		Contingency	**Contingency:** A higher contingency percentage was used to cover the risks of the design
	Ventilation type C	No impact	-
Material reuse and recycling	Recycled gravel	No impact	
Local sourcing of materials	The wood used for the CLT, which is sourced from near the German border. The recycled gravel for the dry ballast comes from local roofs all around the country.	No impact	
Construction optimization	The nature of the materials utilized results in less noise and less heavy equipment.	Construction costs	**Construction costs:** the costs during the construction phase are less because of the methods used and the little time it took.
	2D prefab components make up the primary supporting structure and the facade finishing	Value	**Value:** the construction time is lower which results in a higher value because the income comes sooner.

= negative impact (orange: Construction costs, Additional costs, Contingency under Low carbon materials / Material minimization)

= positive impact (green: Income €/m2 (year), Interest, Carbon credits, Lettable m2, Construction costs and Value under Construction optimization)

4.3 Case Koelmalaan

4.3.1 Case description

Figure 30: Render of project Koelmalaan (Finch Buildings)

At the heart of Alkmaar, a construction project unfolds at Koelmalaan, an initiative by Woonwaard, the owner of the ground. Here, 129 new rental apartments have been developed, comprising a blend of social housing and free-market units, spread across two impressive buildings each with five floors. This diverse housing program includes 59 social rental apartments with 3 rooms and 67 m², 51 medium-priced rental apartments also with 3 rooms but a more spacious 81 m², and 19 social rental one-room studios of 32 m². The social dwellings are financed by Woonwaard and the medium-priced dwellings are financed by Rabobank (Interview 2BA, 2024). These homes were starting to be inhabited in the first quarter of 2023. This project marks a significant step towards sustainable living as each apartment will be connected to HVC's heating network, embracing a gas-free future. Additionally, the installation of solar panels contributes to the sustainability goals of the complex.

The architecture not only embraces sustainability but also community spirit. A unique inner garden, with a greenhouse at its core, will be designed together with the future residents. This green haven serves as a vibrant meeting place where residents can jointly develop activities, giving the project a social function in the neighborhood.

A revolutionary construction technique characterizes the project: the use of solid wood, or cross-laminated timber (CLT), supplied by Finch Buildings. This material is central to the construction of the Netherlands' largest wooden modular residential building, consisting of 260 modules. This method not only provides a rapid construction solution but also underscores a commitment to sustainability. The wood, sourced from sustainably managed forests, offers an environmentally friendly alternative to traditional concrete. Opting for CLT saves a considerable amount of CO_2, approximately 4,800 tons, while the wood itself also captures CO_2, amounting to an additional 1,800 tons. In total, this results in a CO_2 saving of 6,600 tons, equivalent to the impact of more than 17,000 economy flights from Amsterdam to Rome (Finch buildings, 2023).

Table 18: General information of project Koelmalaan

Specification	Koelmalaan
Location	Alkmaar
Size GFA	12.000 m2
Design	2019
Construction time	1 year
Project delivery	February 2023
Developer	Woonwaard
Architect	Finch Buildings
Contractor	De Groot Vroomshoop
Advisors	Aveco de Bondt en Loohuis
MPG score	0,45 €/m2 GFA
Amount of embodied CO2 per m2	-

The developer

Woonwaard is a housing organization located in Alkmaar, Netherlands. They lease around 14,500 residences in the municipalities of Alkmaar and Dijk en Waard. Woonwaard represents the provision of reasonably priced housing that is tailored to your preferences, located in a community that you find appealing, both now and in the long term (Woonwaard, n.d.). They have transformed their concept into a contemporary, process-driven institution and collaborate with their tenants and (chain) partners to achieve their social objectives. Woonwaard has had a two-person board since September 2017 (Interview 2BA, 2024). The introduction of this collegiate board has eliminated the managerial layer, resulting in a more streamlined structure.

Woonwaard places significant emphasis on transparent corporate governance, ensuring that the interests of all individuals are duly considered. As a result, they implement the Governance Code for Housing Corporations. As per this code, Woonwaard has two regulations: A policy has been implemented to safeguard workers who want to report wrongdoing, known as a whistleblower policy. Additionally, an integrity code, often referred to as a code of conduct, has been established. This code applies to the board, employees, and members of the Supervisory Board (Interview 2BA, 2024).

4.3.2 Used embodied carbon reduction strategies

The following table shows a summary of the reduction strategies that were used in Koelmalaan. This information was gathered by doing interviews with the architect and developer involved in this project.

Table 19: Used embodied carbon reduction strategies in Koelmalaan (Interviews + document analysis)

Strategies	Measures	Application
Low-carbon materials	Biobased materials	CLT wood is used for the structure of the building and to store CO2. FAAY retention walls are used for the interior walls of the project.
Material minimization	Optimization of the design	The modular construction method optimizes the design, which results in the minimization of materials that are used for the project.
	Compactness of the building	-

	Prolonging the lifetime of service components	-
	Waste minimization during production and construction	Modular construction was emphasized, which inherently minimizes waste due to the nature of factory production and standardization of parts.
Material reuse and recycling	Reuse	Stone strips are applied over fiberglass mesh, making them easier to replace. This approach is particularly forward-thinking, as it facilitates easier replacement compared to traditional methods.
	Recycling	Recycled ceiling materials are used, which has a small impact but everything counts. They needed it to get the MIA subsidy.
Local sourcing of materials	Prioritizing local materials	-
	Considering the transportation factors	-
Construction optimization	Optimization of construction processes	Modular construction with standardized elements was a key feature of the project, which streamlined the construction process.
	Efficient equipment	-
	Innovative and energy-efficient equipment	The use of electric machinery during construction, including electric high-lifters and part-electric cranes. Also, the construction trailer is built with PV panels and is energy efficient.
	Off-site production procedures	The modular construction approach inherently involved 3D off-site production, resulting in less construction time.

= no impact = positive impact

4.3.3 The decision-making of the developer

This table shows the decision-making process of the developer in general. Furthermore, it shows the project-specific process it went through and how the incorporation of embodied carbon reduction changed the decision-making. The yellow color means the incorporation of embodied carbon reduction has a moderate impact on the decision-making process, the red color has a negative impact, and the green has a positive impact.

Table 20: Decision-making of Woonwaard (Interviews + document analysis)

Steps	Developer general	Project-specific changes when incorporating embodied carbon
1. Recognize and identify	The identification of projects differs every time. So there is not one	They consistently seek projects that can add societal value. In this particular project, reducing CO2 emissions was not the initial focal point. The idea to

	strategy they use at this step.	include CO_2 reduction emerged when a team member watched a television program where this was being implemented and suggested applying it to this project as well.
2. Establish decision-making criteria	Their policy is shaped by the information gathered from all their projects, hence the criteria evolve after each project. There are three main criteria they aim to meet: building flexibly, building circularly, and building quickly.	The Koelmalaan project has established a foundation for their future projects, influencing a shift in their criteria. They now more readily opt for stricter CO_2 reduction requirements, having successfully implemented them before.
3. Search for information	The search for information is very project-specific, so there is no standard strategy	The search for information was more challenging for this project than projects in a traditional way. They needed a lot of advisors and time to figure everything out. The information that was found for project Koelmalaan can now be used for all their future projects. A similar project after Koelmalaan was designed and built in 1 year because of all the information found for this project.
4. Identify options and assess risk	For every project, there is an assessment done to review all the challenges and opportunities of the projects. They look at the long-term investment rather than the short-term investment.	In the business case, there is no substantial reward for constructing a building that reduces CO_2 emissions. Thus, their primary motivations are to create quality housing and maintain a strong reputation in the social market. For Woonwaard, the risks associated with implementing CO_2 reduction decrease as they gain more experience with such projects. However, external parties perceive increased risks because they still find the concept challenging. This modification is being made in anticipation of forthcoming investments in projects that prioritize comparable tactics for reducing CO_2 emissions. Reflecting a long-term strategic approach to decision-making. They also invest more initially in the same project to reduce future renovation costs, a benefit not immediately apparent in the business case. A long-term operation proves more cost-effective than traditional construction methods.
5. Make a decision and implement it	They dare to take risks to successfully enter the market with their projects. Often, this approach succeeds nine times out of ten, acknowledging that	As a social entity, the decision to opt for CO_2 reduction is made more readily than by a commercial entity. This is because they are willing to accept lower commercial returns in favor of greater societal benefits.

	occasional failures are part of the process.	
6. Monitor and reassess the decision	The project is constantly monitored and reassessed to manage the risks. It depends per project how many times this is, but in general, it is the same for every project.	Due to various factors such as the war in Ukraine, adjustments were made to the materials after some trucks were lost. Additionally, the local aesthetic committee (Welstand) was not yet prepared for this type of project. For this project, they had to return to the committee four times before the municipality finally intervened to approve it. This approval process has had lingering effects on their other projects.

= moderate impact = negative impact = positive impact

4.3.4 Used business case parameters

The table below shows which business case parameters Woonwaard used to assess Koelmalaan.

Table 21: Used business case parameters for Koelmalaan (Interviews + document analysis)

Used business case parameters		
Costs	**Income**	**Deal summary**
Gross m2 BVO	Lettable m2	Total project costs
Ratio	Income €/m2 (year)	Total investment value
Amount of units	Indexation	Profit
Construction costs	Income (/year) after index	Profit on costs
Additional costs	VAT	Profit on investment value
Land costs	Yield	Return of equity
Indexation	Value	Internal rate of return
Equity	Subsidies	
Loan		
Interest		
Contingency		

= added parameters

4.3.5 Impact of the embodied carbon reduction strategies on the business case parameters

This table shows the embodied carbon reduction strategies that were used in Koelmalaan and what kind of impact they had on the business case.

Table 22: Impact of the reduction strategies on the business case of Koelmalaan (Interviews + document analysis)

Reduction strategy used	Explanation used measure	Impact on business case	Explanation of the impact
Low carbon materials	Cross-laminated timber (CLT) and laminated timber, is used for the construction. Also, FAAY retention walls are used for the interior walls.	Construction costs	**Construction costs:** The price of the materials is higher than traditional materials.
		Additional costs	**Additional costs:** More expertise was needed so the additional costs were higher for this aspect.
		Income €/m2 (year)	**Income €/m2 (year):** The rent is at the top of the market at this location.
Material minimization	The modular construction method optimizes the design, which results in the minimization of materials and waste for the project.	Additional costs	**Additional costs:** The optimization of the modular method results in less time taken by advisors because a lot is already engineered.
		Construction costs	**Construction costs:** The costs are kept lower because of the little waste and material it produces.
Material reuse and recycling	Reuseable stone strips	No immediate impact	In the long-term, this has a positive effect on the investments that are needed to put in the project in the future.
	Recycled ceiling material	Subsidies	**Subsidies:** By using these recycled ceilings and the other materials a MIA subsidy was granted.
Local sourcing of materials	Sourced from Europe	No impact	
Construction optimization	The use of electric machinery during construction and the energy-efficient construction trailer.	Construction costs	**Construction costs:** the costs during the construction phase are less because of the modular method used and the little time it took.
	Modular 3D prefab elements make up the primary building	Value	**Value:** the construction time is lower which results in a higher value because the income comes sooner.

= negative impact = positive impact

Chapter 5

Multi-case analysis

5 Multi-case analysis

This chapter presents a direct comparison of the outcomes from three separate case studies. These findings are scrutinized to identify any repeating trends or significant differences among them. The key takeaways on how the paradox between embodied carbon development and profitability can be managed are researched in this multi-case analysis.

5.1 General information

Table 23: General information multi-case analysis

	Populus	Sawa	Koelmalaan
Size	25.900	12.000	12.000
Amount of apartments	210	109	129
Size of apartments	-	55 – 80 m2	32 - 81 m2

Each case study employed a turnkey methodology, in which the developer assumes all development-related risks. Following this agreement, a predetermined cost is fixed, and the developer assumes the duty of completing the project within the designated budget, often in conjunction with contractors. The case studies SAWA and Koelmalaan have the same project size, but Populus is more than twice as big. This results in patterns and differences that have to do with the size of the project. As the project size is different the number of apartments is different as well. The interviewees from Populus acknowledged that the larger the development area is the more options there are for implementing embodied carbon reduction strategies.

Key takeaways:

- Holistic area-level sustainability planning: Transitioning focus from individual buildings to entire districts or areas enhances the overall environmental performance and resource efficiency at a larger scale.

5.2 Embodied carbon aspects

Table 24: Embodied carbon aspects for the multi-case analysis

	Populus	Sawa	Koelmalaan
MPG-score	0,56 €/m2 GFA	0,60 €/m2 GFA	0,45 €/m2 GFA
Stored CO2	4.000 kgCO2	5.000 kgCO2	1.800 kgCO2

The MPG technique was used to quantify the embodied carbon in each of the three projects. Although they all use the same quantification, the project team of Populus prefers to quantify it in CO2-eq per m2. Because they are valuing its precision and direct focus on carbon emissions. The lack of a complete database that can be used in a CO2 tracking tool is a major issue in the transition to embodied carbon reduction. The modular building project at Koelmalaan notably delivered superior outcomes. In the case studies, neither carbon offsetting nor carbon taxes were used as financial tools. All the projects included initiatives to store CO2. SAWA had a larger quantity of stored carbon per GFA due to its intensive usage of an extensive wooden structure as the primary support.

Key takeaways:

- Development of a comprehensive database for construction materials: Creating a robust, globally accessible database that provides detailed information on the carbon footprint of construction materials and processes. This database would support informed decision-making, enabling stakeholders to choose environmentally friendly options and track their impact.
- Standardized CO2 tracking tool: Developing a standardized tool for real-time monitoring and management of the CO2 footprint in construction projects. Integrating such tools into project management software like BIM would allow continuous assessment and optimization of environmental impacts at every project stage.

5.3 Location and timeline

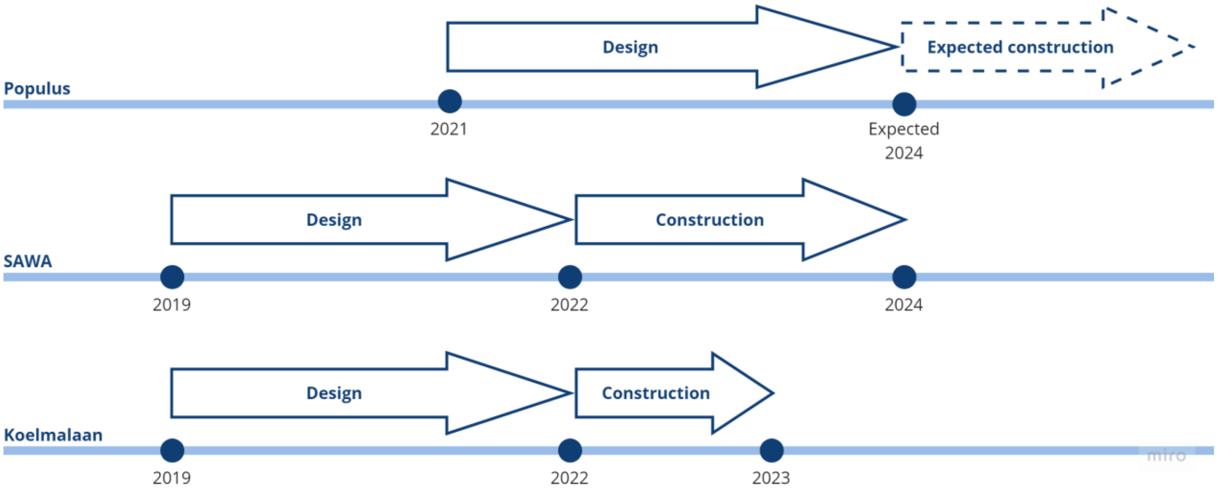

Figure 31: Timeline of the cases (Own illustration)

Populus and Sawa are located in Rotterdam, whereas Koelmalaan is located in Alkmaar. There is a difference in cities, as Rotterdam is a bigger city with a higher population than Alkmaar. This is reflected in Koelmalaan with the municipality and Welstand. Koelmalaan had several obstacles with the local government because they were not used to such innovative projects.

In addition, it is imperative to deliver the assignments following a schedule. The interest rates and material costs associated with the two case studies were considerably lower than they are today, as illustrated by this timeline. In interviews, the developers of Koelmalaan and SAWA made it clear that the project's viability was dependent on the low-interest rates; they further stated that the projects would not have been feasible under the present circumstances of elevated interest rates and material expenses. Therefore, Populus was reassessed and concluded it had to change in order to make it feasible. So the timing of projects has a crucial role in the feasibility of these projects.

5.4 Kind of developer

Table 25: Kind of developer for every case

	AM	NICE	Woonwaard
Type	Sustainable private developer	Sustainable private developer	Housing corporation

Despite differences in focus and target audience, these developers share a common commitment to sustainability and creating value for the community. NICE Developers and AM can be considered 'sustainable private developers' due to their commitment to environmental and social goals within developments, while Woonwaard plays a crucial role as a 'housing corporation' in facilitating accessible and affordable housing. Each of these developers illustrates a unique aspect of sustainable development and the variety within the practice of urban development. NICE Developers and AM face higher initial costs, justified by long-term environmental and financial benefits, whereas Woonwaard focuses on cost-effective sustainable solutions within the constraints of social housing budgets.

5.5 Applied embodied carbon reduction strategies

Table 26: Applied embodied carbon reduction strategies multi-case analysis

Strategies	Measures	Populus	SAWA	Koelmalaan
Low-carbon materials	Biobased materials	Wood FAAY Biocomposite	Wood	Wood FAAY
Material minimization	Optimization of the design	2D flat pack approach and dual layer parking system	Ventilation type C	Modular design
	Compactness of the building	-	-	-
	Prolonging the lifetime of service components	-	-	-
	Waste minimization during production and construction	Fabricated standardized parts	-	Fabricated standardized parts
Material reuse and recycling	Reuse	Urban mining	Roof gravel or dry ballast	Stone strips
	Recycling	-	-	Recycled ceiling material
Local sourcing of materials	Prioritizing local materials	Europe	Europe	Europe
	Considering the transportation factors	-	-	-
Construction optimization	Optimization of construction processes	-	-	Automated factory

	Efficient equipment	-	-	-
	Innovative and energy-efficient equipment	-	-	Electric machinery and construction trailer
	Off-site production procedures	2D prefab flat pack method	2D prefab elements	3D modular units

= Not used   = Partly used   = Used

5.5.1 Low carbon materials

The utilization of biobased materials is a common thread across all analyzed projects, where wood is predominantly used as the primary structural material, excluding the core. This strategic choice is underscored by architectural insights that position wood as a significantly more sustainable alternative to conventional construction materials such as concrete or steel, primarily due to its lower embodied carbon. In the Sawa project, this commitment to wood extends to the façade, enhancing the building's sustainability profile. Conversely, the Populus and Koelmalaan projects employ different materials for their façades: Populus integrates biocomposite panels, and Koelmalaan opts for stone strips, which contribute to varied aesthetic and functional outcomes. Additionally, both Populus and Koelmalaan incorporate FAAY retention walls within their interiors. These walls are currently recognized as the most effective option for reducing embodied carbon in interior applications. This selection not only reflects the ongoing innovations in sustainable building practices but also highlights the projects' commitment to incorporating the most advanced materials available for minimizing environmental impact.

5.5.2 Material minimization

The use of manufactured standardized components in the Populus and Koelmalaan projects is critical to reducing waste throughout the manufacturing and building stages. Populus uses a 2D manufacturing method, while Koelmalaan uses a 3D fabrication technology, both of which improve the design process. These innovations make it easier to create lightweight, modular buildings based on a cohesive grid system, which improves efficiency and sustainability. Furthermore, to accommodate the Populus project's parking needs, a dual-layer parking system was built. This unique method greatly decreased the quantity of concrete and area needed for parking facilities, which aligned with the project's environmental objectives.

The Sawa project used a different approach to material reduction, including Type C ventilation systems. According to discussions with project stakeholders, this choice of ventilation technology resulted in a 60 to 70% decrease in the number of ventilation ducts required. Furthermore, it decreased the need for bigger units, favoring smaller, more cost-effective units. This strategic move resulted in significant cost savings of around €5000 per housing unit, as well as lower maintenance costs, since only the smaller, €500 components need replacement as needed. These metrics demonstrate a deliberate commitment to economic and environmental sustainability in the construction projects.

5.5.3 Material reuse and recycling

All of the projects reviewed used recycled materials as a common method. The Populus project, in particular, used urban mining to source a variety of materials, primarily motivated by the benefits of the Milieu Investeringsaftrek (MIA) subsidy, which incentivizes the use of environmentally friendly practices in real estate projects by providing significant tax breaks. Similarly, the Koelmalaan project used recycled ceiling materials to benefit financially from the MIA subsidy. To be eligible for this subsidy, project investments must meet particular environmental standards, such as energy efficiency and the use of sustainable materials, which the appropriate authorities update on an annual basis. Applications for the MIA are handled by the Netherlands Enterprise Agency (RVO), which ensures that projects correspond to the country's environmental objectives.

The SAWA project employed recycled roof gravel as dry ballast on the Cross-Laminated Timber (CLT) floors that housed the pipe systems. This application not only improved flexibility and demountability, allowing for easier maintenance than previous ways, but it also adhered to sustainable building standards by minimizing the use of new materials. While no direct usage of reused materials was noted in these case studies, the designs contain concepts that enable practically all building components and materials to be dismantled and reused, fostering a circular economy in the construction sector.

5.5.4 Local sourcing of materials

Across all analyzed case studies, the use of FSC-certified wood was consistently observed, demonstrating a dedication to employing this wood derived from responsibly managed forests located in Europe. This strategy may not prioritize the usage of resources derived from the local area, it does demonstrate a more ecologically aware approach compared to importing wood from other continents. This strategic decision demonstrates a conscious focus on sustainable forestry standards, which helps achieve larger environmental goals by decreasing the carbon emissions linked to transporting construction materials across great distances.

5.5.5 Construction optimization

Off-site manufacturing was used in all three case studies. However, the discrepancies in the technique revealed notable disparities in construction efficiency and environmental effect. Populus used 2D prefabricated components mostly for the primary structural parts of the structure throughout construction. SAWA used prefabricated components in 2D for both the primary structure and the exterior finishing, leading to a notable decrease in construction time of around three to six months. On the other hand, Koelmalaan implemented a comprehensive strategy by using modular 3D prefab methods for the primary framework, resulting in a substantial reduction in construction duration of around one year. In addition, the building process of Koelmalaan was notable for its wide use of electric equipment and a completely electric self-sufficient construction trailer, which contributed to the project's sustainability. Off-site manufacturing, namely the use of modular 3D pieces, is widely acknowledged as a superior approach for minimizing embodied carbon in comparison to 2D parts. This is mostly attributed to the shorter building durations and improved efficiency it offers.

Key takeaways:

- Innovative construction methods: Adoption of advanced construction methods and materials, such as prefabrication and modular building, to reduce construction time and optimize resource use

5.6 General decision-making of the developer

Table 27: General desicion-making of the developers multi-case analysis

Steps	AM	NICE	Woonwaard
1. Recognize and identify	The identification of projects differs every time. So there is not one strategy they use at this step.	The identification of projects differs every time. So there is not one strategy they use at this step.	The identification of projects differs every time. So there is not one strategy they use at this step.
2. Establish decision-making criteria	AM has established complicated decision-making because of all the different sectors that all have their own opinion. Overall they want to steer towards a sustainable built environment. These criteria evolve after every project.	The developer set several decision-making criteria, they specifically want to deliver projects that have a positive impact on the built environment. These criteria evolve after every project.	Their policy is shaped by the information gathered from all their projects, hence the criteria evolve after each project. There are three main criteria they aim to meet: building flexibly, building circularly, and building quickly.
3. Search for information	The search for information is very project-specific, so there is no standard strategy.	The search for information is very project-specific, so there is no standard strategy.	The search for information is very project-specific, so there is no standard strategy
4. Identify options and assess risk	For every project, there is an assessment done to review all the challenges and opportunities of the projects. Advisors can be broad in to make sure all the aspects are analyzed.	For every project, there is an assessment done to review all the challenges and opportunities of the projects. Advisors can be broad in to make sure all the aspects are analyzed.	For every project, there is an assessment done to review all the challenges and opportunities of the projects. They look at the long-term investment rather than the short-term investment.
5. Make a decision and implement it	The investment decision is made by the investment team of AM and because they are part of the Royal BAM Group they incorporate their strategies. The returns need to be positive to decide to implement it.	The decision is made by weighing every aspect that is analyzed against the criteria that are set. The decision is always made by the founders of the company. The project has to be feasible.	They dare to take risks to successfully enter the market with their projects. Often, this approach succeeds nine times out of ten, acknowledging that occasional failures are part of the process.
6. Monitor and reassess the decision	The project is constantly monitored and reassessed to manage the risks.	The project is constantly monitored and reassessed to manage the risks.	The project is constantly monitored and reassessed to manage the risks. It depends per project how many times this is, but in general, it

			is the same for every project.

5.6.1 Recognize and identify

The first stage of the decision-making process among the three developers AM, NICE, and Woonwaard emphasizes the need of acknowledging and identifying the distinct characteristics of each project. While their techniques differ, all three organizations recognize that there is no universal plan that can be used to all situations. This demonstrates their adaptable approach that is customized to meet the individual needs of each project. AM and NICE, both private developers, together with Woonwaard, a housing organization, adjust their techniques to the intricacies inherent in each project, emphasizing the need of contextual knowledge in real estate development.

5.6.2 Establish decision-making criteria

When formulating decision-making criteria, AM prioritizes the creation of a sustainable built environment that aligns with the specific and evolving requirements of each project. NICE, in contrast, establishes precise guidelines tailored to developers that flexibly adjust to the probable influence of the project on the constructed surroundings. Woonwaard's criteria are formulated based on data collected from all projects, with the goal of constructing buildings that are efficient, adaptable, and cost-effective. The discrepancy in criterion establishment between private developers and the housing corporation underscores contrasting interests, such as the emphasis on sustainability and impact for AM and NICE, as opposed to the focus on efficiency and cost-effectiveness for Woonwaard.

5.6.3 Search for information

The search for knowledge is characterized as project-specific, without a standardized approach across all three developers. This stage emphasizes the customized strategy that each organization uses, depending extensively on the distinct problems and possibilities given by each project. This strategy enables them to collect pertinent and project-specific data that is crucial for making well-informed decisions, demonstrating a strong capacity to adapt and respond to the demands of the project.

5.6.4 Identify options and assess risk

AM and NICE conduct a comprehensive assessment of the distinctive problems and possibilities of each project, with advisers guaranteeing a full analysis of all areas, in order to identify choices and evaluate risks. Woonwaard, on the other hand, prioritizes long-term investment rather than focusing only on immediate results. This indicates a distinct risk assessment strategy that places importance on sustainability and future viability, rather than immediate profits. This highlights the fundamental disparities in the operational priorities between private developers and a housing organization.

5.6.5 Make a decision and implement it

The process of making decisions in asset management includes the investment team and is in line with the company strategy, with the goal of achieving significant returns. NICE has a comprehensive evaluation process that considers predetermined standards to make judgments, ensuring that all elements of the project align with their strategic goals. On the other hand, Woonwaard strategically evaluates risks to assure the success of their projects within the current market circumstances, demonstrating a more careful approach to implementing decisions. This emphasizes the different degrees of willingness to take risks and the amount of agreement with long-term goals in the decision-making processes between private companies and public housing organizations.

5.6.6. Monitor and reassess the decision

It is essential for all three developers to monitor and review their judgments. AM and NICE consistently evaluate and modify their techniques to properly handle project risks. Woonwaard diligently monitors and evaluates the risks, often commenting on the many versions of the project. The continuous review procedure is crucial for adjusting to changing circumstances and guaranteeing the enduring success and sustainability of their undertakings.

5.7 Decision-making of the developer implementing embodied carbon reduction

Table 28: Decision-making when implementing embodied carbon reduction multi-case analysis

Steps	AM	NICE	Woonwaard
1. Recognize and identify	The project was acquired through a tender from the municipality.	The project was acquired from the municipality of Rotterdam. From now on they will only go for projects/tenders that have CO2 reduction goals. To set an example that building with embodied carbon reduction is feasible.	They consistently seek projects that can add societal value. In this particular project, reducing CO2 emissions was not the initial focal point. The idea to include CO2 reduction emerged when a team member watched a television program where this was being implemented and suggested applying it to this project as well.
2. Establish decision-making criteria	For this project, the criteria included not just CO2 reduction but also enhancing circularity and supporting local biodiversity and inclusivity. The project team had higher criteria than the municipality set during the tender.	The municipality had lower sustainability goals for this project than the architect and developer came up with for this project. This is because they wanted to change the built environment with this project and put their names on the map. The decision-making criteria are expected to change every project because more information is available.	The Koelmalaan project has established a foundation for their future projects, influencing a shift in their criteria. They now more readily opt for stricter CO2 reduction requirements, having successfully implemented them before.

3. Search for information	The search for information was more challenging for this project than projects in a traditional way. They needed a lot of advisors and time to figure everything out.	The search for information was more challenging for this project than projects in a traditional way. They needed a lot of advisors and time to figure everything out.	The search for information was more challenging for this project than projects in a traditional way. They needed a lot of advisors and time to figure everything out.
	The information that was found can now be used for all their future projects. For them, it is an investment in future projects. They are part of the Royal BAM Group which can all profit from the information of this project.	The information that was found for project SAWA can now be used for all their future projects.	The information that was found for project Koelmalaan can now be used for all their future projects. A similar project after Koelmalaan was designed and built in 1 year because of all the information found for this project and the use of the same stakeholders
4. Identify options and assess risk	Willing to accept modified returns on investment by prioritizing sustainability goals and embracing new construction methods like flat pack 2D elements despite potential unknowns and financial risks. One big risk was the influence of the vibrations of the metro on the lightweight structures.	They are willing to modify their anticipated returns for "SAWA" that emphasize not just the amount of carbon contained but also circularity, shared value, biodiversity, inclusiveness, and energy neutrality. During the examination of SAWA, certain risks were detected, such as fire safety issues related to the building, the availability and upkeep of wood, and uncertainties about the financing and its timely acquisition.	In the business case, there is no substantial reward for constructing a building that reduces CO_2 emissions. Thus, their primary motivations are to create quality housing and maintain a strong reputation in the social market. For Woonwaard, the risks associated with implementing CO_2 reduction decrease as they gain more experience with such projects. However, external parties perceive increased risks because they still find the concept challenging.
	After facing these challenges ones the next time it will be more doable. They are investing in the risks right now so they don't	This modification is being made in anticipation of forthcoming investments in projects that prioritize comparable tactics for	This modification is being made in anticipation of forthcoming investments in projects that prioritize comparable tactics for

	have to do it in their next projects.	reducing CO2 emissions. Reflecting a long-term strategic approach to decision-making.	reducing CO2 emissions. Reflecting a long-term strategic approach to decision-making. They also invest more initially in the same project to reduce future renovation costs, a benefit not immediately apparent in the business case. A long-term operation proves more cost-effective than traditional construction methods.
5. Make a decision and implement it	A firm decision was made early in the planning phase to prioritize CO2 reduction strategies, accepting that this would lead to less flexibility in design changes later on.	The decision to build the project with CO2 reduction strategies was made in the initial phase of the project. When this decision is made there is no turning back, which results in less flexibility in the design in further phases.	As a social entity, the decision to opt for CO2 reduction is made more readily than by a commercial entity. This is because they are willing to accept lower commercial returns in favor of greater societal benefits.
6. Monitor and reassess the decision	There's a heightened focus on monitoring due to the innovative nature of the project and the need to manage risks associated with new construction techniques and materials.	Due to the impression of higher risks, the first stages of the project may be subject to more rigorous reassessments in terms of the embodied carbon.	Due to various factors such as the war in Ukraine, adjustments were made to the materials after some trucks were lost. Additionally, the local aesthetic committee (Welstand) was not yet prepared for this type of project. For this project, they had to return to the committee four times before the municipality finally intervened to approve it. This approval process has had lingering effects on their other projects.
	When building with embodied carbon reduction becomes more standard there is no need to do more thorough reassessments. There is no need to implement all the reduction strategies but if everyone uses a couple, the built environment would benefit enormously.	When building with embodied carbon reduction becomes more standard there is no need to do more thorough reassessments. SAWA had no objections from the local community because they implemented participation, suggesting a positive impact on the decision-making process	

		by reducing external project risks.	

☐ = moderate impact ☐ = negative impact ☐ = positive impact

5.7.1 Recognize and identify

The first stage of the decision-making process is acknowledging and pinpointing project-specific possibilities and limitations associated with reducing embodied carbon. AM, NICE, and Woonwaard all use a similar strategy in which they link their project objectives with wider sustainability standards set by municipal bids or corporate policy. AM and NICE secured contracts via municipal bids that established ambitious sustainability standards from the beginning. Woonwaard prioritizes social value and selects projects that match with community wishes and legal permissions, while also considering community and sustainability objectives. This exemplifies a prevalent emphasis on sustainability among developers, but the precise goals may vary depending on the nature of their acquisition procedures and the expectations of their stakeholders.

Key takeaways:

- <u>Regulatory and policy frameworks:</u> Municipal and regulatory frameworks that dictate sustainability standards can shape the broader context within which developers operate, influencing the minimum criteria for project sustainability.

5.7.2 Establish decision-making criteria

AM expands its scope beyond CO2 reduction to include circulation and biodiversity benefits when formulating decision-making criteria. NICE prioritizes tight collaboration with architects to highlight unique sustainability features in their designs, while also including a broader spectrum of environmental effects. Woonwaard utilizes established sustainable techniques from previous experiences as a basis for developing fresh initiatives. AM and NICE take a comprehensive approach to environmental effect, whereas Woonwaard depends on proven processes for new projects. All developers prioritize environmental sustainability in their criteria.

5.7.3 Search for information

In order to successfully execute sustainable initiatives, it is essential for developers to engage in thorough and meticulous information searches. AM and NICE both underline the difficulty of acquiring enough and relevant information to bolster inventive endeavors and underscore the need of drawing lessons from each project to strengthen their tactics for future ventures. Woonwaard also recognizes the need of significant advisory engagement, which reflects a mutual understanding of the requirement for specialist expertise in the adoption of sustainable technologies and practices.

Key takeaways:

- <u>Stakeholder engagement:</u> Actively involve all stakeholders, including investors, tenants, and community members, in sustainability initiatives to ensure alignment and support. Using the same stakeholders might also result in a reduction of costs and time.

- Investment in industry knowledge and skills: Cultivating expertise and innovation through continuous learning and professional development to enhance the industry's capacity to implement sustainable practices.

5.7.4 Identify options and assess risk

AM is open to modifying anticipated profits in order to adopt sustainable practices, seeing these initiatives as an investment in future financial gain. NICE also allows for variable returns, but places more emphasis on the overall sustainability of the project, including biodiversity and circularity features. Woonwaard's risk assessment follows a conventional approach, emphasizing the reduction of risk by using established techniques and materials that guarantee the success and long-term profitability of the project. This underscores a difference in risk tolerance, with AM and NICE being more receptive to adopting unproven techniques in order to achieve wider environmental advantages, whilst Woonwaard maintains a prudent stance towards innovation.

Key takeaways:

- Risk management and innovation adoption: Developers can opt for innovative, albeit riskier, sustainable practices and materials, balancing potential higher costs against long-term environmental and financial benefits.

5.7.5 Make a decision and implement it

The decision-making process in additive manufacturing (AM) involves making early commitments to creative techniques for reducing carbon emissions, which are then included into the planning stages of the project. The decision-making process of NICE is based on a careful consideration of both the environmental advantages and the expected long-term rewards. On the other hand, Woonwaard's choices are shaped by a combination of cost-efficiency and societal advantages, which align with its responsibility as a housing organization dedicated to serving the community's needs. The discrepancies highlight contrasting strategic priorities: private developers (AM and NICE) prioritize environmental innovation and long-term revenue generation, whereas Woonwaard aligns its objectives with immediate community needs and long-term operational sustainability.

5.7.6. Monitor and reassess the decision

Every developer acknowledges the significance of monitoring and evaluation, particularly in light of the dynamic character of sustainable building. AM intends to make continuing adjustments and modifications depending on the results of the project and new insights that arise. NICE is making preparations for any future revisions based on the first performance and external market circumstances. Woonwaard regularly monitors and is prepared to modify depending on community input and project performance evaluations. This stage demonstrates a widespread dedication to being flexible and always becoming better, however the details of their methods for monitoring and reevaluating reflect their own operational and strategic frameworks. A calculation has been done which shows the implementation of hybrid solutions by all developers is more effective than fully implementing all strategies available by just a couple of developers.

Key takeaways:

- Hybrid construction solutions: Combining traditional construction methods with cutting-edge technologies and materials to address complex sustainability challenges.

5.8 Impact of reduction strategies on business case parameters

Table 29: Impact of reduction strategies on business case parameters multi-case analysis

Operational measure used	Measures	Impact on business case Populus	Impact on business case SAWA	Impact on business case Koelmalaan
Low carbon materials	Biobased materials	Construction costs Additional costs Income €/m2 (year) Carbon credits	Construction costs Additional costs Income €/m2 (year) Interest Carbon credits	Construction costs Additional costs Income €/m2 (year)
Material minimization	Optimization of the design	Lettable m2 Construction cost Additional costs	Lettable m2 Contingency	Additional costs
	Compactness of the building	-	-	-
	Prolonging the lifetime of service components	-	-	-
	Waste minimization during production and construction	Construction cost	-	Construction costs
Material reuse and recycling	Reuse	Subsidies	No impact	No immediate impact
	Recycling	-	No impact	Subsidies
Local sourcing of materials	Prioritizing local materials	-	No impact	No impact
	Considering the transportation factors	-	-	-
Construction optimization	Optimization of construction processes	-	Construction costs	-
	Efficient equipment	-	-	-
	Innovative and energy-	-	-	Construction costs

	efficient equipment			
	Off-site production procedures	Value Construction cost	Value	Value

= negative impact = positive impact

5.8.1 Low carbon materials

The use of low-carbon materials, such as cross-laminated timber (CLT), FAAY retention walls, and biocomposite façade panels, in the Populus, SAWA, and Koelmalaan projects results in a significant increase in construction costs. The rise in cost is mostly due to the increased expenditures incurred in acquiring and using ecologically preferable products, as compared to their conventional equivalents. Although there is an initial price penalty, the use of sustainable resources is partially compensated by the eventual economic advantages they provide. These materials are ecologically friendly, which allows all three projects to charge higher rental prices. This is in line with the increasing market demand for eco-friendly living areas. The capacity to impose greater rental fees plays a crucial role in compensating for the initial expenses accrued. Furthermore, the economic feasibility of Populus and SAWA's initiatives is strengthened by their strategic involvement in the carbon credit market. By including carbon sequestration into their project criteria, these initiatives not only make a beneficial contribution to environmental sustainability but also benefit financially by selling carbon credits.

SAWA utilizes its sustainability measures to effectively negotiate a lowering in interest rates for its financing, resulting in a 0.5% reduction. This leads to substantial cost savings during the duration of the loan. In addition, SAWA's proactive environmental efforts, such as the storage of 5,000 tons of CO_2, have allowed it to earn around €400,000 in extra income by selling carbon credits on the Emissions Trading System (ETS). This significant financial infusion further assists in reducing the initial greater expense associated with the use of low-carbon components.

These financial techniques exemplify a holistic approach to sustainable development, in which the initial higher costs are partially offset by the long-term financial and environmental benefits.

Key takeaways:

- Active engagement in carbon credit markets: By incorporating carbon sequestration into their projects, developers can engage in carbon credit markets to help offset higher initial costs with potential revenue from carbon trading.
- Negotiating improved financing terms: Developers can negotiate better financing terms based on the sustainability features of their projects, such as reduced interest rates, which directly impact project profitability.
- Market demand for sustainable living spaces: The increasing consumer demand for eco-friendly living spaces influences rental pricing strategies, allowing developers to command higher rents for sustainable properties.
- Implementation of carbon pricing: Using carbon pricing mechanisms to encourage the adoption of sustainable materials and technologies by making the environmental cost a part of financial decision-making.

5.8.2 Material minimization

The Populus, SAWA, and Koelmalaan projects effectively utilize the technique of material reduction in the field of sustainable development. This method enhances both environmental and economic consequences of construction. This technique, including architectural advances like the 2D flat pack approach in Populus and the modular building methods in Koelmalaan, results in substantial reductions in the use of construction resources and waste generation. These savings obviously decrease the price of construction but also affect other important elements of project economics. Firstly, the reduction of materials has a direct impact on the total area available for rent in a project. SAWA utilizes strategic space planning and material selection, namely via the design of structural columns and incorporation of galleries, to maximize the overall usable area and improve space efficiency. Maximizing the use of space might result in a larger area available for rent, thereby increasing the cash produced per square meter.

Nevertheless, the process of reducing material use also brings up extra expenses and complications. For example, the 2D flat pack and modular methods used in Populus and Koelmalaan efficiently use materials and minimize waste. However, these methods sometimes need the employment of specialist design and building skills. These novel methods may need extra initial expenditures in design and planning to guarantee that reducing material consumption does not undermine the building's structural integrity or aesthetic appeal. Therefore, while the prices of construction may decrease, it is necessary to consider and include the extra expenses related to design and engineering in the overall financial plan of the projects. Moreover, the approach has an impact on the distribution of contingency funds in these projects. The introduction of material reduction tactics, while advantageous, nevertheless brings up uncertainties and hazards related to novel construction technologies and procedures. A greater contingency percentage was used in SAWA to account for the possible hazards linked to the novel design and material utilization. This cautious strategy in financial planning demonstrates a thorough comprehension of the possible deviations and uncertainties that might affect the project as a result of using unconventional building techniques.

In summary, the reduction of materials in these projects successfully lowers construction costs and possibly enhances the rentable space. However, it also requires significant expenditures in specialized expertise and a careful approach to managing risks. The interconnections of these effects highlight the intricate nature of incorporating sustainable practices into real estate construction. This involves finding a balance between cost effectiveness and the need for inventive and risk-conscious project management.

5.8.3 Material reuse and recyling

Material reuse and recycling are essential elements of sustainable construction techniques, as shown by the projects Populus, SAWA, and Koelmalaan. These measures are essential for minimizing the environmental effect of construction by conserving resources and decreasing waste. While the immediate financial advantages of these measures may not be readily apparent, their long-term effects are significantly good, both in terms of the environment and the economy.

Populus demonstrates a dedication to sustainability by embracing urban mining, a technique that includes recovering and repurposing construction materials, which supports larger environmental objectives. Although the immediate cost reductions of employing reused materials may not be immediately evident owing to the complexities of shipping and processing, the project may still benefit from the Milieu Investeringsaftrek (MIA) subsidy. This subsidy incentivizes environmentally friendly behaviors by providing substantial tax benefits, so improving the overall financial feasibility of using recycled materials. Koelmalaan also employs the utilization of MIA to enhance the viability of their business proposition. SAWA's use of reclaimed gravel further emphasizes the project's dedication to sustainable building methodologies. In this context, the reuse of materials does not have an immediate effect on the project's cost structure. Nevertheless, it enhances the project's long-term sustainability credentials, which may have a favorable impact on confidence and property value in the long run.

Key takeaways:

- Subsidies and incentives for sustainable practices: Systemic financial incentives like the MIA subsidy and other government or industry-specific incentives that make adopting sustainable practices more economically feasible.

5.8.4 Local sourcing of materials

The interviewees have found that the existing practice of obtaining materials locally in the Populus, SAWA, and Koelmalaan projects has had very little direct effect on the business case. Nevertheless, there is the possibility of future beneficial consequences on both the ecological footprint and the financial aspects of the project, especially with the development of more regionalized infrastructure for sustainable materials.

The interviewees emphasized the potential advantages of setting up a Dutch facility to produce cross-laminated timber (CLT) together with well-functioning transportation hubs. These developments will greatly decrease transportation emissions and expenses, in line with objectives for reducing embodied carbon and improving economic efficiency. Establishing a local manufacturing capacity would simplify supply chains, eliminate logistical challenges, and perhaps lower material costs. This would have a beneficial impact on the business case and also contribute to sustainability goals.

Key takeaways:

- Establishment of local sustainable material production: Development of local manufacturing capabilities, such as a Dutch CLT factory, to reduce material costs and carbon emissions associated with transportation.
- Streamlining sustainable supply chains: E-logistics, facilitated through centralized hubs, offers a transformative approach to optimizing the transportation and delivery of construction materials. This model minimizes transportation emissions and waste, underscoring the role of digitalization in achieving efficiency and environmental sustainability in construction logistics.

5.8.5 Construction optimization

The projects Populus, SAWA, and Koelmalaan use construction optimization measures, including innovative techniques like prefabrication and modular building, to significantly decrease construction timetables. These strategies are crucial in expediting the construction process, thereby allowing the projects to start producing rental revenue far earlier than conventional construction methods would permit. Through the optimization of construction processes, these projects greatly reduce the duration between the start of construction and the period when the building is ready for use. For example, the use of pre-made components in Populus and modular units in Koelmalaan not only simplifies the construction process and decreases the amount of on-site workers required, but also lessens the impact of weather conditions and schedule problems on project timelines. The decrease in building time immediately results in economic benefits, since it allows developers to begin leasing units sooner. This leads to a higher return on investment by generating money early.

Key takeaways:

- Leveraging the accelerated timber construction: The accelerated adoption of wood construction emerges as a sustainable solution to the urgent housing shortages faced by the Netherlands.

Chapter 6

Expert panel

6. Expert panel

In this chapter, the key takeaways from the multi-case analysis are validated with an expert panel. In the expert panel came forth that developers have different influences on these key takeaways. That's why the key takeaways are split into two; direct influence and indirect influence. Four real estate developers were chosen based on their experience in sustainable development and their active roles in the Dutch real estate market. Their expertise and practical insights were crucial for evaluating the feasibility and impact of the identified findings. Summaries of the key takeaways from the multi-case analysis were prepared, highlighting both direct and indirect influences. These materials served as the basis for discussion.

6.1 Direct influence

Direct influence refers to the immediate and tangible actions that developers can take within their projects to impact embodied carbon reduction and sustainability. These actions are within the developers' control and can be implemented directly in their development processes (Baptista et al, 2023). Direct influences on managing the paradox between net-zero embodied carbon development and profitability include several critical strategies:

- Holistic Area-Level Sustainability Planning: This approach extends the focus beyond individual buildings to entire districts, significantly enhancing environmental performance. However, coordinating such large-scale projects involves multiple stakeholders, extensive planning, and substantial investment, presenting challenges, particularly for smaller developers.
- Innovative Construction Methods: The adoption of prefabrication and modular building techniques can reduce construction time. Nonetheless, challenges include the need for upfront investment in new technology and training. The readiness of the Dutch construction market to fully integrate and scale such innovations may be hindered by existing supply chain structures and workforce training levels.
- Stakeholder Engagement: Engaging all stakeholders, including investors, tenants, and community members, can be challenging due to differing priorities and interests. Aligning stakeholders with sustainability initiatives often requires extensive communication strategies and can slow down decision-making processes. However, using a consistent group of stakeholders for multiple projects can streamline operations and potentially reduce costs and time.
- Balancing Strategies Against Long-Term Benefits: Embracing innovative, sustainable practices involves higher upfront costs and perceived risks, particularly regarding the performance of new materials over time and market acceptance. Balancing these factors with long-term benefits requires a robust risk management framework, which many developers may find resource-intensive to implement.
- Hybrid Construction Solutions: Combining traditional and advanced materials to address sustainability challenges is technically feasible but requires advanced engineering and design capabilities. The cost implications of hybrid approaches need careful evaluation to ensure economic viability.
- Engagement in Carbon Credit Markets: Actively participating in carbon credit markets offers a potential revenue stream to offset higher initial costs. However, navigating these markets requires specific expertise and an understanding of regulatory environments, which can be a barrier for developers new to this area.

- Negotiating Improved Financing Terms: Securing better financing terms based on sustainability features is crucial. Convincing financial institutions of the long-term profitability and risk mitigation provided by sustainable projects can be lengthy and complex.
- Leveraging Accelerated Timber Construction: While wood construction is a sustainable option, practical implementation in the Netherlands faces hurdles such as timber supply constraints and building regulations that may not fully support timber construction yet.

6.2 Indirect influence

Indirect influence encompasses the broader systemic and market-related factors that developers can impact through advocacy, collaboration, and strategic decisions. These influences are not entirely within the developers' immediate control but can significantly shape the environment in which sustainable development occurs (Baptista et al, 2023). Indirect influences involve broader systemic changes that support the net-zero embodied carbon development:

- Comprehensive Database for Materials: Establishing detailed databases and standardized CO2 tracking tools is resource-intensive. While beneficial for long-term sustainability tracking and decision-making, the initial setup and continuous updating represent a significant undertaking.
- Standardized CO2 Tracking Tool: Developing tools to track CO2 emissions consistently across projects is essential for measuring progress toward sustainability goals. To set up a standardized tracking tool requires initial setup and the backing of a lot of stakeholders.
- Regulatory and Policy Frameworks: Municipal and regulatory frameworks are essential for setting sustainability standards but can also restrict developers if standards are not aligned with practical capabilities or change frequently.
- Investment in Knowledge and Skills: Continuous investment in the knowledge and skills required for sustainable construction practices is crucial for long-term success.
- Market Demand for Sustainable Living Spaces: Growing demand for sustainable living spaces is a positive driver. However, translating this demand into profitable ventures depends on effective marketing and the perceived value of sustainability by consumers.
- Implementation of Carbon Pricing: Introducing carbon pricing mechanisms can drive developers to adopt more sustainable practices but requires careful integration with existing financial structures.
- Subsidies for Sustainable Practices: Government subsidies and incentives support sustainability but can be risky due to potential changes in policy with political climates.
- Local Sustainable Material Production: Establishing local production facilities, such as a Dutch CLT factory, is beneficial but requires significant capital investment and government support, which can be challenging to secure.
- Streamlining Sustainable Supply Chains: Implementing e-logistics to optimize material transportation is innovative but requires integration with existing logistics systems, which can be complex and costly.

In summary, while the strategies outlined hold significant promise for managing embodied carbon reduction with profitability, each presents specific challenges that require careful consideration and strategic planning by developers. Real-world implementation will require not only individual company efforts but also broader industry collaboration and supportive regulatory environments.

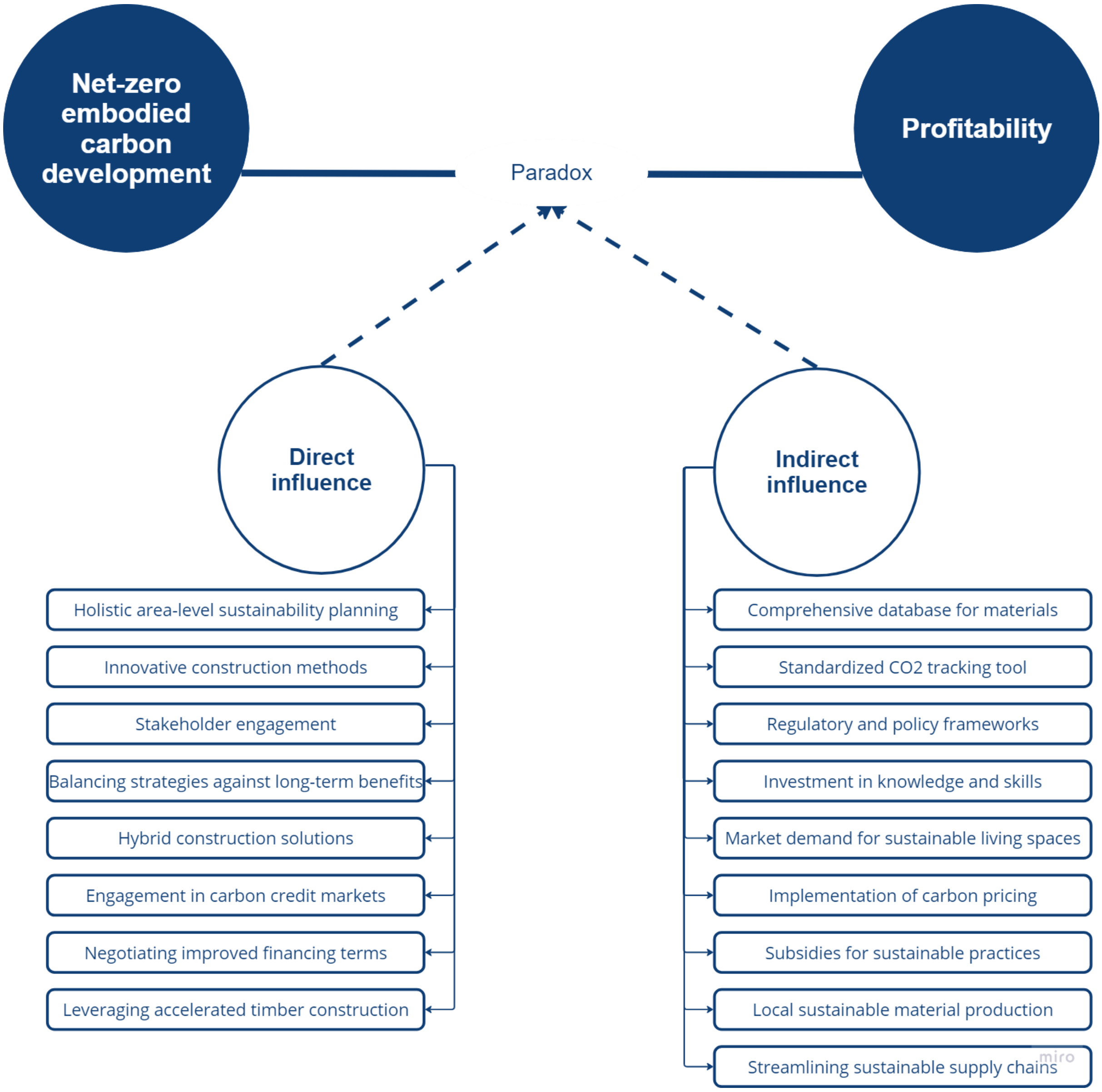

Figure 32: Managing the paradox between embodied carbon reduction and profitability framework (Own illustration)

Chapter 7

Discussion and Limitations

7. Discussion and limitations

The key takeaways from the multi-case analysis and the expert panel validation are the beginning of this discussion. In this discussion the findings are criticized and compared with the findings from the literature, to find similarities and differences.

7.1 Discussion

7.1.1 Embodied carbon definition and quantification

Empirical data has verified that the measurement of carbon emissions embedded in Dutch practices are mostly using Life Cycle Assessments (LCA). These findings are consistent with the study of Amiri et al. (2021), which found that LCA is an extremely sophisticated and well-recognized method of assessing the environmental effects of buildings. In addition, it has been noted that the measurement of carbon emissions in the Netherlands often uses the MPG score, which includes life cycle evaluations to analyze environmental effects.

Nevertheless, certain obstacles have been recognized when using the MPG to measure the amount of embodied carbon. Firstly, the MPG not only quantifies the amount of carbon contained in a product, but also takes into account other compounds that are released, which might diminish the emphasis on carbon measurements. Furthermore, examination of case studies demonstrates that MPG values are comparable for both concrete and wood buildings, despite the latter being considered more environmentally friendly. The Netherlands Enterprise Agency (RVO, 2023) emphasizes that the MPG should give priority to the selection of sustainable construction materials, highlighting the existing mismatch. However, the existing procedures do not successfully accomplish this, especially due to the insufficient representation of wood in module D of the MPG. Wood is often burned rather than recycled, resulting in significant carbon dioxide emissions, as emphasized by the respondents. The suggestion is that by making wood demountable, it might be reused more easily, leading to a reduction in its environmental impact and improving the efficacy of the MPG in addressing environmental issues.

Moreover, the representation of the MPG as euros per square meter of gross floor area per year presents intricacies. This statistic incorporates the societal costs associated with preventing environmental impacts, in addition to the price of standard treatments, for each effect. The NMD database calculates the Environmental Cost Indicator (ECI) as the shadow cost per unit of material. Nevertheless, this approach conceals the precise amount of CO2 emissions per square meter, making it more challenging to efficiently control and communicate within the sector.

Considering these concerns, the PPm, which specifically pertains to the amount of CO2 emissions per Gross Floor Area, seems to be a more suitable measurement for projects that want to minimize embodied carbon. It offers a more precise and relevant assessment of the environmental footprint. Hence, it is essential for Dutch legislation to include not only the MPG but also the PPm in order to enhance the efficacy of CO2 emission reduction in construction projects.

7.1.2 Embodied carbon reduction strategies

The examination of the case studies indicated that the measures used to reduce embodied carbon were in line with those highlighted in the existing body of research. Significantly, several solutions were notably chosen for their substantial influence in lowering CO2 emissions. The case studies all showed a clear preference for using wood right from the beginning of the projects, especially in structural applications, because of its significant impact on reducing CO2 emissions. These data from González and Navarro (2006), and Sham et al. (2011) provide support for the idea that replacing conventional materials with ecologically friendly alternatives might potentially decrease CO2 emissions by around

33%. This highlights the crucial need of carefully choosing materials in order to reduce carbon emissions. Nevertheless, the use of wood instead of concrete is impeded by the existing price and evaluation system under the MPG framework. Concrete continues to be cheaper, and the environmental effect ratings fail to adequately distinguish between the two materials. Nevertheless, the typical approach involves using recycled concrete and FSC-certified wood obtained from Europe, which guarantees shorter transit distances and sustainable forestry practices.

Furthermore, the use of tactics aimed at reducing material consumption, such as the decreased utilization of equipment and the enhancement of design efficiency, were often utilized and shown to be successful. These findings align with the studies conducted by Akbarnezhad & Xiao (2017) and Nadoushani & Akbarnezhad (2015), which established a correlation between lower embodied carbon and decreased material amounts. Yeo & Gabba (2011) and Pomponi & Moncaster (2016) provide more evidence that an efficient design may greatly reduce the amount of materials needed. For example, implementing ventilation type C in the projects resulted in a significant decrease of 60 to 70% in the need for ventilation ducts, while favoring the use of smaller and more economically efficient units. Likewise, by streamlining building procedures, there was a 30% decrease in the use of concrete and reinforcing steel.

Moreover, the investigations highlighted a significant use of manufacturing methods, like the incorporation of prefab components and modular systems. The use of prefabrication for façade components and the desire to build structures using prefabricated technologies were motivated by their ability to significantly reduce embodied carbon. Modular modules, specifically, were very efficient because of the significant level of prefabrication feasible. This not only reduces building time but also lowers the need to transfer personnel and supplies to the site.

The three most influential techniques discovered, namely material selection, structural design, and service systems, are intimately related to the Life Cycle Assessment (LCA) stages A1–A3 which are called the product stages and stages B2 & B5 which are called the replacement stages. The association is supported by recent studies conducted by, Rasmussen et al. (2018), and Röck et al. (2020), which highlight the fundamental importance of these measures in successfully reducing embodied carbon.

7.1.3 Decision-making when incorporating embodied carbon reduction

1. Recognize and Identify

The first phase in the decision-making process, which is essential for all three developers AM, NICE, and Woonwaard, is to acknowledge and recognize the distinct attributes of each project. This step is crucial, as every developer recognizes the lack of a universal method and adjusts their techniques to the specific details of each project. This versatility is further emphasized by the incorporation of embodied carbon reduction. Developers integrate project aims with larger sustainability goals in response to municipal bids and corporate policies that establish rigorous sustainability criteria. The convergence between the goals of AM and NICE is especially evident, since they successfully obtained contracts by prioritizing sustainability in their bids to municipalities. Meanwhile, Woonwaard places a high priority on social value, ensuring that their projects are in line with the wishes of the community and sustainability objectives. This change exemplifies a proactive stance towards sustainability, while the precise objectives may differ based on stakeholder expectations and acquisition procedures.

2. Establish Decision-Making Criteria

When developing criteria for decision-making, AM goes beyond only reducing CO2 emissions. Instead, they also consider circularity and biodiversity, demonstrating a comprehensive approach to sustainability. NICE prioritizes cooperation with architects to include distinctive sustainability elements into projects, expanding the range of environmental factors taken into account. Woonwaard customizes criteria based on established sustainable practices from previous projects to encourage creativity in new ventures. This exemplifies a discrepancy in the formulation of criteria, as commercial developers such as AM and NICE give priority to comprehensive environmental implications, while Woonwaard relies on existing techniques for innovation.

3. Search for information

The process of searching for information involves the need for comprehensive, project-specific data to bolster sustainable activities. The organizations AM and NICE emphasize the difficulty of finding sufficient knowledge to enable creative ventures, emphasizing the significance of learning from past experiences for future undertakings. Woonwaard recognizes the need of extensive advisory participation, demonstrating a mutual agreement among developers about the requirement for specialized expertise in implementing sustainable technologies and processes.

4. Identify Options and Assess Risk

Developers exhibit a distinct variance in their risk assessment methodologies. AM is prepared to modify projected earnings to account for sustainable activities, seeing them as investments in future benefits. NICE also enables adaptability in returns, prioritizing the entire durability of initiatives, including biodiversity and circularity. In contrast, Woonwaard adheres to a traditional methodology, prioritizing the reduction of risks via the use of recognized methodologies to guarantee the achievement of project objectives and sustained profitability over time. This suggests that different degrees of willingness to take risks exist, with private developers being more receptive to creative methods that provide wider environmental advantages, whilst Woonwaard follows more cautious tactics.

5. Make a Decision and Implement It

The decision-making process at this level unveils clear strategic objectives. AM and NICE have made first promises to include new strategies that reduce carbon emissions into their project planning. NICE carefully weighs the advantages for the environment with the potential long-term benefits, but Woonwaard's choices are guided by cost-effectiveness and the advantages for society, which is in line with its function as a housing organization. This emphasizes a strategy contrast in which private developers prioritize environmental innovation and future profitability, while Woonwaard focuses on urgent community needs and operational sustainability.

6. Monitor and Reassess the Decision

Monitoring and reassessment are essential for developers, as they demonstrate a dedication to adaptability and improvement in sustainable construction techniques. AM makes continuous revisions depending on project results and developing insights. NICE is making preparations for future changes that will be impacted by the first performance and market circumstances. Woonwaard demonstrates a commitment to being sensitive to community input and project performance assessments, showing their continual focus to being adaptable and continuously improving within their operational and strategic frameworks.

Incorporating the reduction of embodied carbon into the decision-making processes of developers presents both difficulties and possibilities. Developers exhibit flexibility and a dedication to sustainability, but their methods are influenced by different degrees of risk tolerance and strategic goals. The results emphasize the need of ongoing innovation, adaptable risk assessment methodologies, and thorough monitoring to improve the long-term viability of the constructed environment. This conversation emphasizes the dynamic nature of sustainable practices in real estate development and the need for developers to constantly adjust and improve their decision-making processes in accordance with rising sustainability standards and stakeholder expectations.

7.1.4 Embodied carbon reduction impact on business case

Low carbon materials

The integration of low carbon materials such as cross-laminated timber (CLT), FAAY retention walls, and biocomposite façade panels into construction projects represents a significant evolution towards sustainable development. However, this transition brings with it complex economic implications that are currently the subject of considerable debate among developers, investors, and policymakers. The crux of this discussion revolves around the higher initial costs of these materials compared to traditional counterparts, driven by factors like limited production capacities, emerging technologies, and developing supply chains.

One central argument hinges on the economic justification of these higher costs. Skeptics argue that the premium paid for low carbon materials may not always be recoverable in the current market, where tenant and buyer willingness to pay more for sustainable features can vary significantly by region and economic climate. On the other hand, proponents cite a strengthening trend in consumer preference for eco-friendly living spaces, suggesting that this shift will increasingly justify the initial financial outlay. Furthermore, projects like SAWA that leverage sustainability measures to secure lower financing rates and generate additional revenue through carbon credits demonstrate innovative financial strategies that can help balance the cost equation. These financial incentives are pivotal in enhancing the economic case for sustainable materials. However, the reliability and consistency of such incentives are heavily dependent on the regulatory landscape and economic policies, introducing a layer of financial uncertainty. Developers may face risks in overestimating the availability of these incentives, leading to potential miscalculations in their project budgets.

The long-term environmental benefits of low carbon materials such as reduced carbon footprints, compliance with anticipated environmental regulations, and potential energy efficiency improvements are well acknowledged. These benefits align with global sustainability targets and evolving consumer demands. Yet, the translation of these environmental advantages into direct economic returns is a topic of ongoing debate. The ability of the real estate market to fully value sustainability features in terms of property valuation and rental rates is not uniformly mature across all regions, which adds another layer of complexity to investment decisions in sustainable materials.

Moreover, the strategic risks associated with adopting low carbon materials, including supply chain vulnerabilities and the pace of technological advancements, must be carefully weighed against the potential for future regulatory changes favoring or mandating the use of sustainable materials. This risk management debate focuses on whether the potential regulatory shifts and changing market preferences justify the initial higher costs and related risks.

Material minimization

The strategy of material minimization, as employed in the Populus, SAWA, and Koelmalaan projects, showcases an essential facet of sustainable development, focusing on reducing resource use and waste during construction. This approach, which incorporates techniques like 2D flat pack and modular building methods, offers significant direct economic benefits by lowering construction costs. However, the adoption of material minimization raises complex discussions surrounding its broader economic impact and the feasibility of such strategies from a business perspective.

The immediate advantage of material minimization is clear: reducing the volume of materials used directly cuts down on procurement and waste management costs. For example, architectural innovations like the flat pack system in Populus and modular methods in Koelmalaan not only reduce the raw material needed but also streamline the assembly process, making construction quicker and less labor-intensive. This efficiency translates into cost savings, which ideally would enhance the project's profitability. However, the transition to using minimized material approaches introduces additional complexities, particularly in terms of the need for specialized design and engineering expertise. The design processes for these innovative construction methods are often more complex and require advanced technical skills, which can add to the initial project costs. The challenge here lies in determining whether the savings from reduced material use outweigh the increased expenses in design and planning. Critics argue that while the operational costs are lowered, the upfront investment in intellectual and design capital can dilute these savings, making the financial benefits less compelling.

Moreover, the strategic implementation of material minimization has implications for project risk management. The innovative nature of these construction techniques may introduce uncertainties related to the structural integrity and long-term durability of the buildings. Developers must manage these risks, balancing the innovative aspects of material reduction against potential future liabilities. This requires a careful analysis of the trade-offs between immediate cost savings and the possibility of unforeseen future costs related to material performance and maintenance.

Additionally, the approach impacts the spatial configuration and potential revenue generation of a project. By optimizing the use of space, as seen in SAWA's strategic material selection and design, developers can potentially increase the rentable area, thus enhancing revenue. However, this benefit must be carefully weighed against the market's readiness to accept and value the optimized spaces, which may differ from traditional layouts.

Material reuse and recycling

Material reuse and recycling are pivotal strategies within sustainable construction, aiming to minimize environmental impact by conserving resources and reducing waste. The projects like Populus, SAWA, and Koelmalaan have implemented these strategies, each highlighting a commitment to enhancing environmental sustainability. However, the adoption of material reuse and recycling is not merely a straightforward decision—it involves complex considerations of economic implications, logistical challenges, and market perceptions, which are central to current debates within the construction industry.

The primary advantage of reusing and recycling materials is the clear environmental benefit: reducing the demand for virgin materials, which in turn decreases the overall carbon footprint and waste production of construction projects. This sustainable practice aligns with global environmental goals and growing regulatory pressures to reduce waste and emissions. From an economic standpoint, these strategies can potentially lower material costs by utilizing less expensive recycled or repurposed materials instead of new, often costlier, resources. However, the financial benefits of material reuse and recycling are not always immediately apparent and can vary significantly depending on several factors. One major challenge is the logistics involved in sourcing, transporting, and processing reused materials. These activities can introduce additional costs, which might offset the savings from using cheaper materials. For example, the Populus project employs urban mining techniques, which, while environmentally commendable, involve complexities related to the separation, treatment, and integration of recycled materials into new construction. These processes require specialized equipment and expertise, potentially increasing upfront costs.

Moreover, projects benefitting from financial incentives like the Milieu Investeringsaftrek (MIA) subsidy illustrate how regulatory support can enhance the economic viability of using recycled materials. However, reliance on such incentives introduces an element of financial uncertainty, as these policies can change based on shifts in political and economic landscapes. This dependency on external financial mechanisms raises questions about the long-term economic sustainability of relying heavily on recycled materials in construction projects.

Another important aspect to consider is the market's perception of buildings constructed with recycled materials. While there is a growing consumer appreciation for sustainability, the perception and valuation of reused materials can vary. Potential tenants or buyers might have concerns about the quality, durability, and aesthetic appeal of recycled materials, which could impact rental or sale prices. Developers must navigate these market perceptions carefully to ensure that their projects are both economically viable and attractive to potential clients

Local sourcing of materials

Local sourcing of materials in construction projects like Populus, SAWA, and Koelmalaan forms an essential part of sustainable building practices, focusing on reducing the environmental impacts associated with transportation emissions and promoting regional economies. However, integrating locally sourced materials into construction projects sparks considerable debate over its practicality, economic implications, and overall effectiveness in achieving sustainability goals.

The primary advantage of local sourcing is its potential to decrease carbon emissions related to transporting materials over long distances. This aligns with broader environmental objectives to reduce the carbon footprint of construction activities. Additionally, by supporting local suppliers and industries, developers can stimulate local economies, which may foster stronger community ties and potentially expedite material procurement processes.

Despite these benefits, the economic viability of local sourcing remains a contentious issue. One significant challenge is the availability and variety of locally sourced materials, which can be limited depending on the region's resources and industrial capacity. For instance, while a project might prefer to use locally sourced timber, the regional availability of quality or specific types of timber suitable for construction may be lacking. This limitation could force developers to choose between using less ideal materials or facing the higher costs and environmental impacts of importing materials. Moreover, the cost competitiveness of locally sourced materials is not guaranteed. Local suppliers might offer higher prices due to smaller scale operations or higher production costs compared to larger, established suppliers who benefit from economies of scale. This price variance can make locally sourced materials less attractive from a financial standpoint, especially for projects where budget constraints are tight.

Financial incentives and policy support can play a crucial role in mitigating some of these challenges. For example, tax incentives for using local materials or government subsidies aimed at boosting local industries can help offset the higher costs associated with local sourcing. However, reliance on such incentives introduces uncertainty into project planning, as these policies can change with shifting political landscapes. Additionally, there's a debate about the long-term sustainability and strategic benefit of local sourcing. While it clearly supports immediate environmental goals, its impact on the overall sustainability of construction practices can depend significantly on the management and sustainability practices of the local suppliers themselves. For instance, if local material production itself is not managed sustainably, the benefits of reduced transportation emissions could be negated by environmentally harmful production processes.

Local sourcing also involves navigating market perceptions. Projects utilizing local materials effectively can market these properties as environmentally friendly, potentially attracting tenants and buyers interested in sustainable living. However, this marketing advantage depends heavily on consumer awareness and values, which can vary widely by region.

The expert panel has verified these difficulties, specifically emphasizing that obtaining local manufacturing facilities, such as a Dutch CLT plant, is advantageous but requires substantial financial investment and political backing, which might be difficult to get. This highlights the need of forming strategic alliances and implementing favorable legislation to improve the practicality of using low carbon materials.

Construction optimization

Construction optimization, particularly through techniques like prefabrication and modular building, is a significant aspect of modern sustainable construction projects, as demonstrated by Populus, SAWA, and Koelmalaan. This strategy is focused on enhancing efficiency, reducing waste, and shortening construction timelines. However, the adoption of construction optimization techniques involves complex evaluations regarding their impact on cost, project timelines, labor dynamics, and overall project quality, which are central to ongoing debates in the construction industry.

The primary advantage of construction optimization is its potential to drastically reduce the time from project inception to completion. By using prefabricated elements or modular units, significant portions of the construction work are transferred from the site to a factory setting. This controlled environment allows for greater precision, fewer weather-related delays, and reduced waste generation. For developers, these factors translate into lower labor costs, minimized risk of delays, and potentially lower overall project costs. However, the economic implications of construction optimization are nuanced and invite critical examination. While the direct costs associated with construction activities, such as labor and on-site time, are reduced, there are substantial upfront investments required in the design and fabrication processes. The design of modular or prefabricated elements often involves sophisticated technology and may require specialized architectural and engineering expertise. These initial costs can be substantial and may not always be fully recoverable through the efficiencies gained during the construction phase.

Moreover, the reliance on prefabrication and modular techniques can introduce logistical challenges, particularly related to transportation and assembly. The size and weight of prefabricated modules might necessitate special transportation logistics, which can add to the overall cost of construction. Additionally, the assembly of these modules on site must be executed with high precision; any misalignments can lead to significant delays and additional costs, potentially negating some of the anticipated efficiencies.

Another key point of debate concerns the impact of construction optimization on project quality and market perception. While modern prefabrication techniques have advanced significantly, there remains a perception among some buyers and tenants that modular or prefabricated buildings are inferior to those constructed using traditional methods. This perception can affect the marketability and pricing power of such properties, influencing the overall return on investment for developers.

Furthermore, construction optimization is often touted for its environmental benefits, such as reduced waste and lower on-site energy use. However, the full environmental impact of these techniques must consider the entire lifecycle of the construction materials and processes. For instance, the production of modular units in a factory setting may lead to higher energy consumption and emissions than those avoided on-site, raising questions about the net environmental benefit of these approaches.

7.2 Limitations

Although this study makes a good contribution to the advancement of a more resilient built environment, it is important to recognize several constraints that might impact the results. The study was done under a limited time schedule, which required making research selections that prioritized time efficiency rather than just focusing on enhancing research findings. A significant constraint arises from the scope of the cases and the quantity of developers questioned. The scarcity of case studies and interviews may have compromised the strength and reliability of the results. However, by narrowing down the number of examples, it was possible to thoroughly examine each incident, enabling extensive cross-case analysis. Although the sample size was modest, the interviews uncovered noteworthy parallels and contrasts across the instances, hence strengthening the overall validity of the study.

Limitations connected to the content also arose, namely with the context of the cases and the interpretation of the findings. The developers decision-making process and business cases were mostly conducted a few years ago, taking into account market circumstances that varied in terms of borrowing rates and material prices. During that period, the idea of embodied carbon was still new and there was not much experience in using it, which might have affected the comprehension and incorporation of this notion in decision-making processes. Furthermore, subsequent to the conclusion of these investigations, there may have been the emergence of novel understandings or legislation that might have an impact on existing decision-making frameworks.

Moreover, the clustering of the case studies in specific geographic locations may impact the applicability of the results, since different developers and cities may have varying assumptions about the characteristics of the business case. Moreover, the presence of many developers, including one housing company and two private developers, leads to a range of different operating techniques. Housing companies often follow distinct strategy frameworks in contrast to private developers. Appraisers have a crucial impact on the choices made by these developers, especially in the areas of property appraisals and long-term financial planning.

Finally, it is crucial to acknowledge that this study was conducted specifically in the Dutch context, which may restrict its relevance in other regulatory or market settings. These variables emphasize the need of carefully analyzing the research findings and indicate areas that should be further investigated to strengthen the reliability and relevance of the results in wider settings.

Chapter 8

Conclusion and Recommendations

8. Conclusion and recommendations

8.1 Conclusion

8.1.1 Subquestion one

How can embodied carbon in real estate development be assessed?

Embodied carbon refers to the whole amount of greenhouse gas emissions produced during the full lifespan of a structure. This encompasses emissions generated during the whole life cycle of building components, including those arising from raw material extraction, transportation, production, construction procedures, maintenance, replacement, and the disposal or recycling of components at the end of their useful life. The measurement of embodied carbon is systematically conducted via the use of Life Cycle Assessment (LCA) methods. This technique assesses the environmental consequences associated with a structure or product across its full duration of existence. The equation used to measure the amount of carbon embodied in a material is given by:

Material quantity (kg) x carbon factor (kgCO2e/kg) = embodied carbon (kgCO2e)

The direct and indirect carbon emissions associated with every stage of a building's life cycle, manufacture, development, utilization, and disposal—are included in a life cycle assessment (LCA). Carbon emissions mostly originate during the processing and preparation of raw materials throughout the product stage. Though to differing degrees, the stages of replacement, end-of-life, and maintenance all add to the total environmental impact. The elements of construction, including the frame and service systems, are significant contributors to embodied carbon emissions, accounting for roughly 36% and 32% respectively. The quantification of embodied carbon in Dutch construction practices is now done using the Environmental Performance of Buildings (Milieuprestatie Gebouwen - MPG) metric. Nevertheless, the Paris Proof Material-related Indicator (PPm) is increasingly being recognized as a possibly more appropriate measure for assessing the carbon emissions associated with materials used in various construction projects. Both MPG and PPm use the Life Cycle Assessment (LCA) framework to evaluate and measure environmental effects, providing a strong method for monitoring and reducing the carbon footprint linked to building development and operation.

8.1.2 Subquestion two

Which regulations for embodied carbon in building projects are in place now and may be implemented in the future, and which ones could affect the decision-making of developers?

The changing regulations regarding the amount of carbon emissions produced during building projects, especially in Europe, have significant consequences for decision-making. The regulatory framework has a lot of different aspects each has influence on every other aspect in it.

Environmental rules in Europe, such as the European Green Deal, set high goals for lowering the amount of carbon emissions associated with products and processes. In the Netherlands, the Environmental Performance of Buildings (MPG) measure encourages the use of sustainable materials to reduce the amount of carbon emissions produced during the construction process. The purpose of these laws is to not only reduce the environmental effect of both new and existing buildings, but also to guide the construction sector towards adopting more sustainable methods.

In the near future, the Energy Performance of Buildings Directive IV (EPBD IV) will require the building industry to achieve even more significant reductions in emissions, same goes for the revisions to the European Green Deal. The revisions include the implementation of sustainability standards for construction materials and the obligatory calculation of Global Warming Potential (GWP) for new structures, which will be in effect from 2027. This sets a new standard for the real estate sector. Simultaneously, the Sustainable Finance Disclosure Regulation (SFDR) and the Corporate Sustainability Reporting Directive (CSRD) are improving the clarity about the environmental sustainability effects of investments. These requirements necessitate comprehensive disclosures, with the aim of providing information and exerting an impact on the decision-making. Moreover, the EU Taxonomy, an essential element of these rules, has a crucial function in delineating sustainable economic activity. This taxonomy facilitates the allocation of green funding by providing clarity on which activities may be classified as ecologically sustainable. As a result, it has a substantial impact on decision-making in the construction industry.

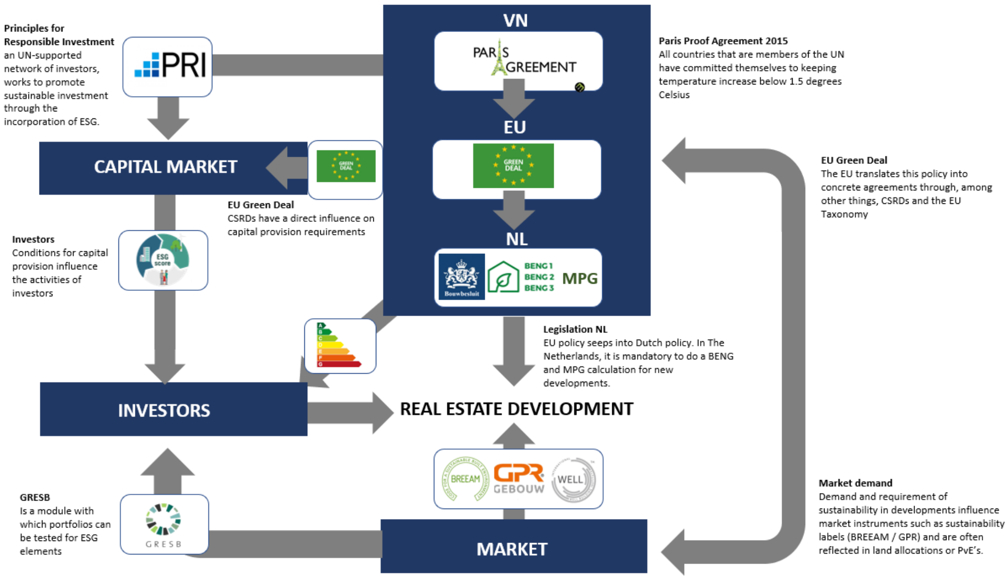

Figure 33: Regulations for embodied carbon framework (Own illustration)

These regulatory initiatives aim to incorporate environmental sustainability into the practices of the financial and construction sectors. They highlight the important relationship between regulatory frameworks and decision-making in the current European context.

8.1.3 Subquestion three

What strategies are currently available to developers to reduce embodied carbon in their projects and how are they used in practice?

In order to reduce the amount of carbon emissions associated with building projects, a range of operational techniques and procedures are used. Both theoretical frameworks and practical data support these findings. These include using low-carbon materials, minimizing and reducing resources, reusing and recycling materials, procuring materials and components locally, and optimizing building processes. The figure provided illustrates the precise operational measures that were applied and the corresponding scope within the evaluated projects.

Table 30: Conclusion of the used reduction strategies

Strategies	Measures
Low-carbon materials	Biobased materials
Material minimization	Optimization of the design
	Compactness of the building
	Prolonging the lifetime of service components
	Waste minimization during production and construction
Material reuse and recycling	Reuse
	Recycling
Local sourcing of materials	Prioritizing local materials
	Considering the transportation factors
Construction optimization	Optimization of construction processes
	Efficient equipment
	Innovative and energy-efficient equipment
	Off-site production procedures

= Not used   = Partly used   = Used

These tactics are evident via intentional decisions on materials and building methods. Case studies continuously show a strong inclination towards using wood, a well-established material with low carbon content, widely from the early stages of projects to minimize CO_2 emissions, highlighting its crucial role in the building phase. It is important to mention that all the wood used is certified by the Forest Stewardship Council (FSC) and comes from Europe. This guarantees sustainability and reduces transportation distances compared to wood supplied from outside Europe.

Furthermore, the approach of minimizing and reducing materials is seen in projects that use strategies such as limiting the usage of mechanical installations. Within this particular setting, the widespread use of natural ventilation systems, namely Type C ventilation, arises as a highly favored option. Additionally, a case study emphasizes that the optimization of structural design and facade finishing has a crucial role in minimizing the amount of emissions. recycled materials, such as recycled roof gravel and eco-friendly concrete versions, are utilised instead of typical cast-in-place concrete to improve the environmental impact of these projects. Waste minimization and efficient transportation planning are also crucial factors in construction. These goals are accomplished by closely monitoring and reducing energy and water consumption, minimizing the usage of packaging materials, implementing transportation e-hubs and establishing factories closeby.

Lastly, the use of off-site manufacturing methods, which include the utilization of pre-made components and modular modules, is consistently seen in all of the case studies. This method significantly reduces the amount of carbon dioxide released into the atmosphere by shortening the time it takes to build, decreasing the number of transportation trips, and subsequently lowering the CO_2 emissions produced during construction.

8.1.4 Subquestion four

How much does the consideration of reducing embodied carbon factor into the decision-making process of developers in present practice?

The examination of many cases demonstrates that developers take into account the reduction of embodied carbon as an important aspect in their decision-making process. However, the degree and method of incorporating this consideration varied across various organizations. Developers like AM, NICE, and Woonwaard demonstrate their dedication to harmonizing project-specific objectives with wider sustainability criteria established by municipal tenders or company policy. The linkage between sustainability aims and project recognition and identification is apparent from the first phases, as developers integrate these objectives to ensure contract acquisition and compliance with community and legal obligations.

The use of criteria for decision-making highlights the significant emphasis put on minimizing embodied carbon. Developers embrace a holistic strategy that extends beyond just reducing CO_2 emissions to include circularity and biodiversity advantages. AM and NICE prioritize working closely with architects to include distinctive sustainability elements, whilst Woonwaard depends on established sustainable methods to provide novel initiatives. All of them set the criteria to only use genuine reduction strategies, they stay away from any greenwashing. This demonstrates a significant emphasis on promoting genuine environmental sustainability in various decision-making frameworks.

During the information search phase, developers emphasize the need of obtaining comprehensive and pertinent data to bolster sustainable projects. The difficulties related to collecting enough information are recognized, indicating a shared awareness of the significance of expertise and advisory involvement in effectively carrying out sustainable activities. Stakeholder engagement is crucial during this phase, as it guarantees the involvement of investors, renters, and community members, which in turn ensures that sustainability efforts are in line with their interests and receives their support. Developers exhibit varying degrees of risk tolerance as shown by risk assessment and option selection. AM and NICE demonstrate a readiness to adjust projected revenues and returns to include sustainable practices, seeing them as long-term investments in future benefits. On the other hand, Woonwaard takes a traditional approach, giving greater importance to reducing risks by using well-established methods and materials. This discrepancy demonstrates a range of risk management approaches, where private developers are more inclined towards embracing novel and maybe more hazardous sustainable solutions.

The decision-making and execution phases emphasize the strategic disparities across developers. AM and NICE have made early commitments to include novel carbon reduction measures into their project design in order to gain long-term environmental and financial advantages. On the other hand, Woonwaard's choices are influenced by cost-effectiveness and the benefits to society, which is in line with its goal as a housing organization that prioritizes the community. The strategic objectives highlight the many reasons that drive sustainability initiatives in the real estate industry. Ultimately, the monitoring and evaluation phase highlights the ever-changing aspect of sustainable building. Every developer acknowledges the significance of ongoing assessment and adjustment in response to project results and fresh perspectives. The dedication to adaptability and improvement is a recurring theme, albeit the particular approaches to monitoring and reevaluation vary based on various operational and strategic frameworks. The investigation determines that hybrid building solutions, which integrate conventional techniques with cutting-edge technology and materials, are especially efficient in tackling sustainability concerns.

Reducing embodied carbon is crucial in the decision-making process of real estate developers. The extent to which sustainability impacts choices may vary, but there is a definite and increasing focus on sustainability across the industry. The rise in sustainable practices in real estate development is primarily influenced by legislative frameworks, market needs, and the inherent advantages they provide. This highlights the importance of ongoing innovation and strategic adaptation in this field.

8.1.5 Subquestion five

What modifications do developers make to the business case parameters to implement strategies aimed at reducing embodied carbon?

Based on the data, it can be inferred that developers make only little changes to their business case parameters when applying specific techniques to reduce embodied carbon. These modifications were noted in two main approaches.

The first approach that has a direct influence on business case characteristics is the use of low-carbon materials, namely FSC-certified wood. Integrating wood into building may enhance the original property value as a result of the elevated expenses associated with supplies and construction. Nevertheless, the use of wood, both in terms of structural components and as an outside surface, has had an adverse effect on operating costs. This may be mostly attributed to the lack of expertise and uncertainty that is often referred to when using wood for the construction of a building. One important component is the business case advantages, like reduced interest rates on loans, which are essential for ensuring the financial viability of the projects. Moreover, the capacity of the building to store CO2 enables the opportunity to sell carbon credits, so introducing an additional aspect to the financial advantages. Another advantage is the expected increase in market prices due to the building's excellent quality and the usage of wood. As a consequence, the need for future improvements is reduced since it is expected that the reduction strategies that are used would improve its overall quality and demand, thereby lowering risk.

The other technique that affects the parameters of the business case is optimizing construction, namely via operational measures such as using prefabricated pieces and off-site manufacture. Modular components or prefabricated pieces were used in all three case studies, resulting in improved construction time parameters and cash flow.

8.1.6 Research question

How can developers manage the paradox between profitability and embodied carbon reduction?

To successfully address the conflict between maximizing profits and reducing embodied carbon in real estate development, a complex interaction is needed between initiatives driven by developers and wider systemic pressures. By doing a thorough examination of several case studies and literature, it is clear that developers have the capacity to greatly impact the sustainability of their projects, even when faced with economic and operational obstacles.

From the standpoint of developers, comprehensive area-level sustainability planning emerges as a vital technique. Shifting the emphasis from individual buildings to whole districts enables improved environmental performance and resource efficiency on a broader level. The implementation of this technique requires thorough preparation and coordination among several stakeholders, highlighting the intricate nature of incorporating sustainability on a larger scale.

The use of low-carbon materials, such as cross-laminated timber (CLT), FAAY retaining walls, and biocomposite façade panels, indicates a strong dedication to sustainability. Despite the greater upfront expenses associated with these materials in comparison to conventional materials, the long-term advantages, such as possible income from carbon credits and the opportunity to charge higher rents for environmentally friendly homes, justify the original investment. Incorporating these materials not only decreases the negative impact on the environment but also corresponds with the increasing market need for eco-friendly living environments. Material reduction tactics, shown via the use of 2D flat pack and modular construction techniques, provide significant economic advantages by decreasing resource consumption and waste generation. These methods reduce building expenses and also improve the amount of space available for rent, hence boosting income. Nevertheless, implementing these groundbreaking techniques requires certain skills in design and engineering, which might counterbalance the potential financial benefits.

Utilizing material reuse and recycling is crucial for minimizing the environmental consequences of construction. Projects such as Populus, SAWA, and Koelmalaan have successfully applied these techniques and have received financial incentives, such as the Milieu Investeringsaftrek (MIA) subsidy, as a result. Although the immediate financial gains may not be immediately obvious, the long-term environmental and economic benefits highlight the significance of integrating recycled materials into building projects. The practice of procuring materials locally, although now not significantly affecting the business case, shows potential for future sustainability and economic efficiency. Implementing local manufacturing facilities, such as a Dutch Cross-Laminated Timber (CLT) facility, has the potential to greatly decrease both transportation emissions and expenses. Implementing this approach would simplify supply chains, minimize logistical obstacles, and perhaps reduce material costs, thereby improving the economic feasibility of sustainable building.

Construction optimization, using methods such as prefabrication and modular building, substantially decreases construction schedules and expenses. These techniques provide enhanced accuracy, less interruptions, and decreased inefficiency, resulting in early creation of rental income and increased investment returns. Nevertheless, these endeavors need a significant initial capital outlay for both design and technology, which presents an initial financial obstacle.

Efficient involvement of stakeholders is crucial for ensuring that sustainability activities are in line with the concerns and priorities of investors, renters, and community members. Adopting cutting-edge, environmentally-friendly methods requires investing more money at the beginning and dealing with potential uncertainties, which makes it crucial to have a strong system for managing and mitigating risks. Developers must carefully weigh these risks against the long-term environmental and financial advantages, frequently necessitating a meticulous reevaluation of conventional profit projections.

Participating actively in carbon credit markets offers a viable approach to counterbalancing the higher initial expenses. Developers may gain extra income via carbon trading by integrating carbon sequestration into their projects. However, successfully navigating these marketplaces requires specialized skills and a comprehensive comprehension of regulatory frameworks. Obtaining more favorable funding arrangements that are contingent on sustainability characteristics is essential but difficult. Persuading finance institutions of the enduring profitability and risk reduction offered by sustainable projects requires extensive and intricate talks.

Fundamental modifications are required to bolster developers' endeavors. Comprehensive databases and standardized CO2 monitoring systems are necessary for making well-informed decisions and continuously evaluating environmental implications. It is necessary for municipal and regulatory frameworks to establish sustainable criteria that are consistent and in line with realistic capabilities.

The growing market demand for environmentally sustainable living spaces might result in increased rental rates for eco-friendly houses, leading to lucrative business opportunities. Government subsidies and incentives are essential for ensuring the economic viability of sustainable practices, however their dependence creates financial unpredictability. Implementing local manufacturing plants for eco-friendly materials and optimizing supply chains via electronic logistics are cutting-edge approaches that need substantial financial commitment and governmental backing. These structural reforms are necessary to enhance the efforts of developers and guarantee that sustainable building techniques become commercially feasible and broadly embraced.

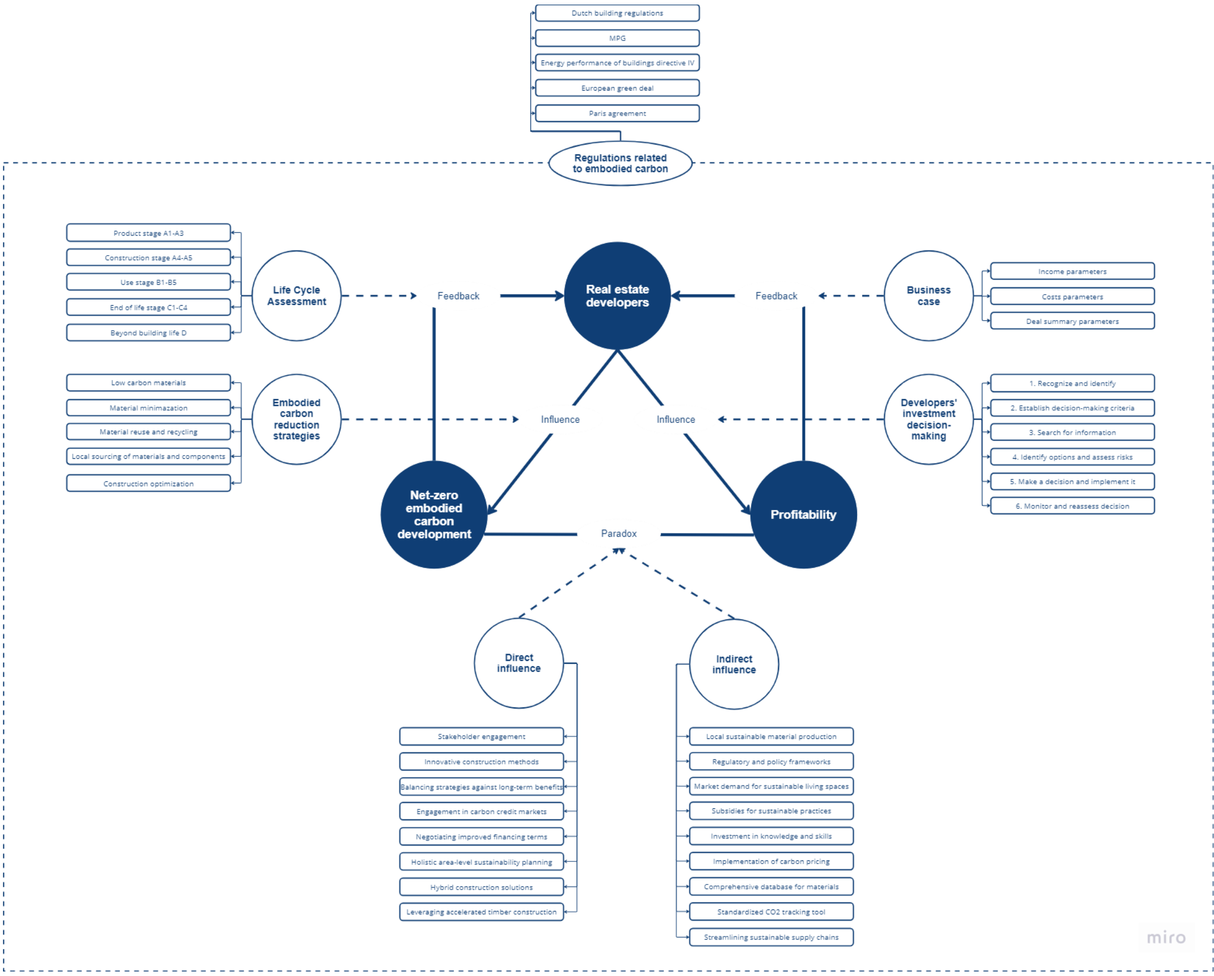

Figure 34: Framework for developers to manage the paradox (Own illustration)

Ultimately, real estate developers may reconcile the paradox between profitability and reducing embodied carbon by using a blend of strategic planning, inventive building techniques, successful stakeholder involvement, and comprehensive assistance. Developers may attain enduring environmental and economic advantages by incorporating sustainability into their fundamental processes and capitalizing on financial incentives. Concurrently, there is a need for alterations in policy, market demand, and infrastructure to bolster and enhance these endeavors, guaranteeing the extensive use of sustainable building techniques. The figure above shows the framework that developers can use to start managing the paradox.

8.2 Recommendations

8.2.1 Practice recommendations

This chapter showcases the practical recommendations according to this research, to make sure that developers start implementing embodied carbon reduction.

1. Encourage Hybrid Solutions and Collaborative Knowledge Sharing: Developers should start by concentrating on putting hybrid solutions into practice in order to successfully handle the contradiction between embodied carbon reduction and profitability. These solutions will help the steady development of expertise and experience in low-carbon building techniques by fusing conventional and sustainable techniques. Municipalities and other stakeholders must to use hybrid strategies at the same time to increase their comprehension. Among developers, investors, municipalities, and other stakeholders, open and honest communication is essential. Cogent and knowledgeable decision-making will result from cooperative sharing of ideas and resolution of uncertainty about costs, rewards, and risks. This combination promotes a more coordinated and successful strategy to lowering embodied carbon by allowing developers to make proactive changes and early resolution of any problems.

2. Improve Embodied Carbon Quantification Methods: To be accurate and relevant, current embodied carbon quantification techniques, including the MPG (MilieuPrestatie Gebouwen) computation, need to be revised. For example, the need for more accurate separation is shown by the fact that both concrete and wood may provide the same MPG rating. Furthermore, because direct steering with the PPm (Per Perceel meter) is directly related to CO2 emissions per Gross Floor Area (GFA), it should be given higher priority as a more relevant statistic for assessing environmental effect. All relevant data points must be included in the more accurate and extensive underlying database to enable these computations. Moreover, creating a CO2 tracking tool will help designers and developers to make wise choices all along the project lifetime, guaranteeing ongoing embodied carbon level monitoring and optimization. To efficiently lower CO2 emissions, Dutch laws must thus include both MPG and PPm. With this dual strategy, the building sector would have a better view and more successful environmental plans.

3. Improve Incentives for Embodied Carbon Reduction: Government and commercial parties must significantly raise incentives to promote the broad adoption of methods that lower embodied carbon. Although developers may already choose to modify conventional models, widespread use is hampered by the absence of uniform incentives. Promoting loan reductions, subsidies, and carbon credit models may encourage developers to include low-carbon procedures into their regular business operations. All by themselves, however, these incentives are inadequate. To impose and quicken the shift to sustainable building methods, the government must support them with strict rules or CO2 price mechanisms, like a carbon tax. The building sector will be driven to considerable reductions in embodied carbon by this twin strategy of incentives and regulatory actions.

8.2.2 Scientific recommendations

In order to further our comprehension of the intricate relationship between profitability and the reduction of embodied carbon in building, many potential areas for future study are suggested. The purpose of these proposals is to enhance the understanding gained from this research and tackle developing patterns and uncertainties in the industry.

1. The influence of market conditions on the reduction of embodied carbon: Further investigation is needed to understand how existing and changing market conditions, such as fluctuations in interest rates, shifts in regulatory environments, and variations in construction costs, impact the decision-making processes involved in reducing embodied carbon. This may include doing meticulous investigations that concentrate on certain facets of the Discounted Cash Flow (DCF) model or conducting comprehensive research including various geographical locations and property categories, such as office spaces and retail assets. An worldwide comparative research might provide useful insights into how various market variables impact the priority and execution of carbon reduction measures.

2. Impact of Carbon Taxation and Carbon Credits on Investments: The effects of carbon tax regimes on investment strategies need comprehensive investigation, especially in countries like Germany where these policies are actively developing. Furthermore, it is essential to do comprehensive study on the implementation of carbon credits, specifically focusing on the transparency of allocation procedures, accountability for compensating actions, and systems to guarantee the long-term storage of CO_2. Gaining a comprehensive understanding of these elements is essential for successfully incorporating carbon pricing into investment models and decision-making processes.

3. The impact of certification on investment choices: This might provide insights into how these certificates affect behavior and market values. Moreover, it is crucial to define a universally accepted definition of a "Paris Proof" building in order to maintain uniformity and dependability in certification procedures, as well as to bolster its legitimacy and market acceptance. There is a need to quantify the correct numbers of the consequences of trying to get the certifications. By quantifying the numbers a real conclusion can be drawn and the exact effects can be researched and used by others.

By engaging in these research activities, researchers and practitioners may get a deeper understanding of the obstacles and motivators that impact the acceptance of sustainable practices within the construction sector. This increased comprehension will assist in formulating more efficient strategies and regulations that harmonize economic incentives with environmental sustainability objectives, thereby expediting a shift towards more sustainable building methods on a worldwide scale.

Chapter 9

Reflection

9. Reflection

This thesis is positioned within the wider discussion of Sustainability transitions and the transformation of port cities. Although embodied carbon is not the main focus of this topic, it is inherently connected to the ongoing sustainability transition that is of the upmost importance for the construction industry. The curriculum of Management in the Built Environment (MBE), has historically included the study of investment decision-making. Traditionally, these conversations have not taken into account the concept of sustainability, particularly the influence of embodied carbon on the financial justification. This study aimed to create a new link between the sustainability and the decision-making of developers with their business case. The MBE program focuses on developing innovative ideas for the construction and maintenance of real estate, with an emphasis on improving the sustainability of the built environment. The primary purpose of this research is to steer developers with effective solutions to reduce embodied carbon and increase profitability. Additionally, it aims to contribute to the overall sustainability of the built environment. This study makes a substantial contribution to decreasing the carbon footprint linked to construction and building activities. The proposal suggests significant improvements to the conventional decision-making procedures, in line with the overall sustainability objectives of the MSc in Architecture, Urbanism, and Building Sciences program. This connection demonstrates the importance and currentness of incorporating sustainability-focused initiatives within the traditional frameworks of real estate investment decision-making.

Method

This thesis used a qualitative empirical study technique, which began by completing an extensive literature analysis in four main areas: reducing embodied carbon, rules pertaining to embedded carbon, decision-making processes of developers, and the financial justification. The literature review section dedicated to embodied carbon and associated techniques for reduction had a substantial amount of current and reliable sources. However, due to limited time, there may have been an insufficient conceptual model, perhaps leaving out subsequent advancements and understandings. The limited scope of the research also impacted the analysis of rules related to embodied carbon, requiring a concise review method. Furthermore, the examination of the process of making investment decisions was guided by the frameworks proposed by Gehner (2008) and Willows et al. (2003). The dependence on these rather outdated sources may have impaired the current significance of the results. Although there were limits, the approaches used in the literature review and framework construction offered significant assistance, making it easier to communicate effectively with and explain to interview participants in later phases.

The empirical aspect of the research included conducting exploratory interviews, which was chosen due to the novelty of the issue and the lack of available data. The purpose of these interviews was to first evaluate and improve the existing frameworks related to reducing embodied carbon and determining the parameters of the business case. Consequently, both frameworks were revised, with only minimal alterations, maybe due to the small number of respondents. However, the first understanding of the method led to improved interviews with a more profound understanding. Case studies were used to augment the practical significance of the results and anchor them in the actualities of the development sector. The task of choosing appropriate cases was challenging because of the rarity of projects that include numerous approaches to reduce embodied carbon, including different developers and architects. Out of the first eight possible Dutch case studies found, only three were finally selected for the investigation. These case studies played a crucial role in clarifying the impacts of reduction measures and making the conclusions more tangible, especially during interviews with developers. Significantly, our interviews revealed that the majority of developers were highly aware of the precise steps used to mitigate embodied carbon and the resulting ramifications. The architects' knowledge provided a comprehensive understanding of the practical application of this topic.

The data for the case studies were mostly obtained via semi-structured interviews and documentary analysis, which were well-suited to the study aims. The interviews were systematically arranged, starting with architects and then on to developers. This methodical approach not only made the process of collecting information more efficient but also encouraged more thorough and detailed replies. A further analysis was undertaken using a multiple-case study approach, which enabled a comparative review of the data to identify clear trends and draw conclusions. Atlas.TI was used for data analysis in this procedure, with preset codes helping to organize and compare the findings.

Process

Upon contemplation of my thesis journey, I found great satisfaction in the graduating process, which was both instructive and fulfilling. Exploring the concept of sustainable changes in the construction industry, especially from a financial perspective, perfectly matches my enthusiasm for creative involvement. The availability of several analytical methods in the course greatly assisted this investigation, resulting in a diversified and enriching academic experience. The choice to concentrate on urban development from the viewpoint of a developer was shaped by my early partnerships and talks with my mentor Erwin. These interactions enhanced my comprehension and honed my research emphasis.

The transition from the starting phase (P1) to the completion phase (P4) was characterized by several obstacles and chances for growth and development. At first, the advancement through these stages was hindered by personal obligations and a lack of clarity in conveying the qualitative character of my study to my supervisors, resulting in some uncertainty. Nevertheless, after a time of relaxation between P2 and the start of my investigation, I was able to review and improve my approach with more clarity and concentration. The transition time was essential as it enabled me to better prepare for meetings with my supervisors and prevent significant complications throughout the implementation of my study. The counsel provided by my advisers, Erwin and Angela, was crucial throughout the whole procedure. They facilitated the seamless integration of ideas and the establishment of a coherent framework for my thesis. Although my thoughts was first chaotic, their help allowed me to clarify my ideas and successfully integrate many components of my research. Nevertheless, the expedition encountered several logistical obstacles, particularly during the period of arranging and carrying out interviews with prospective case study organizations. This time instilled in me the significance of adaptability and tenacity, traits that were crucial in surmounting the challenges presented by the dependence on other entities.

As the thesis approached its final stages, the comprehensive examination of three specific Dutch case studies uncovered significant trends that were essential for making conclusions regarding the effects of techniques aimed at reducing embodied carbon on the financial viability of the project. The study, in conjunction with the empirical data collected via semi-structured interviews, emphasized the need of testing research results against present market realities to improve their credibility. Upon consideration, this analysis emphasizes the significance of careful and thorough planning and preparation, especially when it comes to coordinating with other entities. It also reinforces my dedication to connecting theoretical study with actual implementation in the realm of sustainable real estate investing.

Balance between working and writing my thesis

An enlightening experience that offered a well-rounded mix of academic study and genuine industry exposure was working for the real estate company NEOO while completing my thesis. The flexibility and assistance of the company were essential in allowing me to get into my thesis topic in-depth and obtain priceless insights outside of my particular field. Because NEOO gave me the option to choose my thesis topic, I was able to match my academic goals with my career goals. Having this independence helped to create a feeling of ownership and drive all through the study. Whenever I had to spend more time on my thesis, NEOO made it possible for me to put my academic obligations ahead of my job obligations, therefore establishing a healthy balance between the two. The atmosphere of support within the company went beyond flexibility. NEOO actively helped to arrange important parts of my study, like setting up interviews with professionals in the field. Rich, practical insights made possible by this access to experts really improved the empirical part of my thesis. Regular conversations with NEOO staff members also gave me the chance to hear insightful opinions and helpful criticism on my work. These conversations allowed me to hone my concepts and methodology, which strengthened and expanded my thesis.

All things considered, my thesis writing and my position at NEOO worked really well together. Along with expanding my knowledge of sustainable real estate development, the practical experience and academic flexibility I had enhanced my readiness for upcoming obstacles in the industry. My study was made richer and more significant by the cooperation with NEOO.

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Appendices

Appendix 1 Interview references

Exploratory interviews:

Interview 1A (2023), Developer from NEOO, developers perspective on embodied carbon

Interview 1B (2023), Senior developer from NEOO, implementation of embodied carbon company-wide

Interview 1C (2024), Architect from LEVS Architects, embodied carbon reduction strategies

Semi-structured case study interviews:

Interview 2AA (2024), Developer + architect SAWA, case study

Interview 2BA (2024), Developers Koelmalaan, case study

Interview 2BB (2024), Architect Koelmalaan, case study

Interview 2CA (2024), Developers Populus, case study

Interview 2CB (2024), Architect Populus, case study

Appendix 2 Interview checkpoints

Pre-interview Preparations

- Send the interview invitation
- Obtain signed informed consent form
- Provide time and location details (including Teams link if applicable)
- Set up Teams and recording equipment

Start of the Interview

- Thank the interviewee for participating
- Confirm informed consent
- Inform the interviewee about the recording and request verbal consent again
- Start Teams and backup audio recording device
- Provide a brief introduction of the researcher and the study

Post-interview Checklist

- Ask if the interviewee has any additional comments or questions
- Briefly explain the validation procedure
- Inform the interviewee that the thesis can be shared upon request
- Send a thank-you email with the interview transcript

Appendix 3 Informed consent interviews

Geïnformeerde toestemming

Delft, **DATUM**

Geachte heer/mevrouw,

Dit interview is onderdeel van een afstudeeronderzoek voor de TUDelft voor de master Management in The Built Environment aan de faculteit Bouwkunde. Dit onderzoek wordt gedaan door Tom Oskam en zal ook het interview afnemen.

Het onderzoek gaat over het volgende: Er wordt steeds meer nadruk gelegd op het verminderen van de hoeveelheid koolstof die in gebouwen aanwezig is, aangezien de vastgoedsector een grote bijdrager is aan de uitstoot van broeikasgassen. Ondanks dit vormen een aantal uitdagingen, met economische beperkingen voorop, een obstakel voor de vooruitgang in betekenisvolle koolstofreductie. Opvallend is het gebrek aan onderzoek dat zich richt op deze financiële kwesties vanuit het perspectief van ontwikkelaars, en de weinige studies die er zijn, missen soms diepgaande analyse en praktische oplossingen. Het heroverwegen van de investeringsbesluitvorming van ontwikkelaars is cruciaal, vooral in het licht van de erkenning van de industrie van de noodzaak om koolstofemissies te verminderen, in het bijzonder met betrekking tot embodied carbon. Maar het integreren van deze nieuwe inzichten in bruikbare modellen blijft een uitdagende taak. Daarom is de onderzoeksvraag: *"Hoe kunnen ontwikkelaars zich navigeren in de paradox tussen winstgevendheid en materiaalgebonden CO2-reductie?"*

Door deze vraag te beantwoorden, wordt de kennis over de manieren waarop de perspectieven van ontwikkelaars worden beïnvloed door financiële factoren bij het integreren van strategieën voor het verminderen van embodied carbon in investeringsbeslissingen verbeterd.

U bent niet verplicht om mee te doen aan het onderzoek. U kunt altijd uw medewerking aan het onderzoek zonder opgaaf van redenen intrekken en vragen om uw gegevens te vernietigen. U mag ook iedere vraag die wij stellen, weigeren te beantwoorden.

Wij beloven dat wij zorgvuldig met uw gegevens omgaan, en dat de gegevens op een beveiligde Europese server worden bewaard met een password voor extra beveiliging. Het document waarin wij bijhouden onder welke code uw gegevens worden verwerkt, zullen we ook met een extra password beveiligen en op een andere plek bewaren. Dit sleuteldocument zullen we 5 jaar na de laatste wetenschappelijke publicatie over dit onderzoek vernietigen.

Als u vragen heeft over dit onderzoek, kunt u contact met mij opnemen: Tom Oskam

Als u mee wilt doen aan dit onderzoek, wilt u dan de bijgaande verklaring invullen en ondertekenen?

Met vriendelijke groet,

Tom Oskam

	Ja	Nee
(1) Ik verklaar dat ik de informatiebrief d.d. **DATUM** heb gelezen of deze brief is aan mij voorgelezen. Ik heb deze informatie begrepen. Daarnaast heb ik de mogelijkheid gekregen om hier vragen over te stellen en deze vragen zijn naar tevredenheid beantwoord.	□	□
(2) Ik verklaar hierbij dat ik vrijwillig meedoe aan dit onderzoek. Ik begrijp dat ik mag weigeren om vragen te beantwoorden en dat ik mijn medewerking aan dit onderzoek op elk moment kan stoppen zonder opgave van reden. Ik begrijp dat het meedoen aan dit onderzoek betekent dat mijn antwoorden worden bewaard.	□	□
(3) Ik begrijp dat het geluidsmateriaal (of de bewerking daarvan) en de overige verzamelde gegevens uitsluitend voor analyse en wetenschappelijke presentatie en publicaties zal worden gebruikt.	□	□
(4) Ik begrijp dat de opgeslagen gegevens onder een code worden bewaard en anoniem worden verwerkt.	□	□
(5) ik geef hierbij apart toestemming dat de geanonimiseerde gegevens in de toekomst ook door andere onderzoekers mogen worden gebruikt.	□	□

Ik heb dit formulier gelezen of het formulier is mij voorgelezen en ik stem in met deelname aan het onderzoek.

Plaats: _______________ Datum:_______________

_ (Volledige naam, in blokletters)

_ (Handtekening geïnterviewde)

‘Wij hebben toelichting gegeven op het onderzoek. Wij verklaren ons bereid nog opkomende vragen over het onderzoek naar vermogen te beantwoorden.’

Naam onderzoeker(s)

Tom Oskam

Appendix 4 Exploratory interview protocol developer

Interview protocol

Goedemorgen/Middag,

Hartelijk dank voor uw bereidheid om deel te nemen aan dit interview. Voordat ik begin, zal ik mezelf even voorstellen. Ik ben Tom, een student die de master Track Management in The Built Environment volgt aan de TU Delft. Op dit moment bevindt ik me in de laatste fase van mijn masteropleiding. Het uitvoeren van dit interview dient daarbij een belangrijk en leerzaam onderdeel voor het afstuderen. Ik kijk ernaar uit om uw waardevolle inzichten te verkrijgen en te gebruiken om onze kennis op het gebied van onderzoek te vergroten.

Graag zou ik uw toestemming vragen voor het opnemen van het interview, met als doel het vergemakkelijken van de transcriptie en het voeren van een vloeiend gesprek. De opnames zullen worden getranscribeerd en geanonimiseerd. Als u akkoord gaat met deze voorwaarden, wil ik u vragen het toestemmingsformulier te ondertekenen.

Starten met opname en opnieuw om toestemming vragen op opname

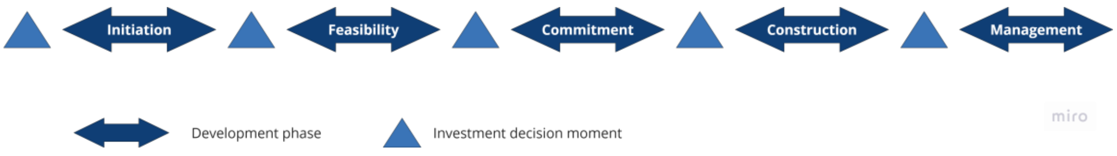
Om uw toestemming ook op de opname te hebben, herhaal ik wat ik net gezegd heb en zou ik u willen vragen ook voor de opname in uitgesproken woorden uw toestemming te verlenen. *Herhalen vorige alinea*

Algemene vragen:

1. Kunt u zichzelf kort voorstellen en iets vertellen over uw achtergrond?
    a. Wat is uw rol en wat zijn u verantwoordelijkheden in u bedrijf?
2. Hoe worden projecten voornamelijk aangenomen?
    a. Met eigen vermogen?
    b. gedelegeerd?
3. Wat weet u al over embodied carbon en de impact op de business case?

Investering beslismomenten:

Ik zal beginnen met de specifiekere vragen, die betrekking hebben op het investering beslisproces. Ik zal dit doen met behulp van het volgende framework (dat ik aan de interviewde zal geven in de vorm van een A4). Ik zal een korte toelichting geven en dan wat vragen stellen over de manier waarop jullie dit doet en of dit verandert als gevolg van het verminderen van embodied carbon.



Investment decision-making activities:	Explanation:
1. Recognize and identify	Ten eerste moet er erkenning zijn dat een project op de markt is en dat de ontwikkelaar geïnteresseerd is in een investering.
2. Establish decision-making criteria	Zowel organisatie- als projectdoelstellingen spelen een belangrijke rol bij een investeringsbeslissing; deze criteria kunnen standaarden zijn voor alle projecten of per project.
3. Search for information	Het zoeken naar informatie wordt als voorwaardelijk beschouwd en is nodig om verschillende varianten te kunnen maken.
4. Identify options and assess risk	Verschillende varianten moeten gemaakt worden waarna doormiddel van een business case een haalbaarheidstoets zal worden gedaan.
5. Make a decision and implement it	De verschillende opties voor de ontwikkeling worden verkend en geanalyseerd. Waarna een keuze gemaakt moet worden of er doorgegaan of gestopt wordt.
6. Monitor and reassess the decision	Als er door wordt gegaan zal de keuze steeds opnieuw nagelopen moeten worden met de business case ernaast om de juiste keuzes te blijven maken.

In dit framework zijn dus 6 stappen te zien die aangeven hoe een investering beslismoment is gestructureerd volgens mijn literatuuronderzoek.

4. Zijn deze investeringsbeslissing activiteiten representatief voor jullie eigen beslissingsmomenten?

5. Zijn er verschillen tussen deze stappen en de stappen die jullie zelf altijd belopen?
    a. Kunt u het proces dat jullie volgen in uw eigen woorden uitleggen?

<u>1 Recognize and identify</u>

6. Hoe vinden jullie potentiële projecten?

7. Hoe beslis je dat je als ontwikkelaar in eerste instantie geïnteresseerd bent in een project?
    a. Worden tijdens de recognition stap duurzaamheidsaspecten zoals embodied carbon meegenomen?

<u>2 Establish decision-making criteria</u>

8. Hebben jullie bepaalde algemene criteria die jullie volgen als bedrijf?
    a. En wat zijn voorbeelden van project specifieke criteria die jullie wel is tegenkomen?
    b. Hoe worden deze criteria opgeschreven en bijgehouden?

9. Wordt er binnen deze criteria ook iets gezegd over duurzaamheid?
    a. En wordt hier embodied carbon in meegenomen

3 Search of information

10. Hoe wordt de informatie voor de potentiële projecten verzameld?

11. Zoeken jullie ook naar informatie over duurzaamheid tijdens deze stap?
    a. En zit hier dan ook embodied carbon informatie bij?

4 Identify options and assess risk

12. Hoe vertaal je de gevonden informatie in de juiste varianten die uitgezocht gaan worden?

13. Nemen jullie in de varianten duurzaamheidsaspecten mee?
    a. Zit in die duurzaamheidsaspecten ook embodied carbon?

14. Kunt u de financiële modellen beschrijven die u gebruikt om potentiële ontwikkelingsprojecten te evalueren?

15. Hoe balanceert u risico en rendement bij uw beleggingsbeslissingen?
    a. Veranderd er iets aan de balans tussen risico en rendement wanneer embodied carbon wordt meegenomen?

5 Make a decision and implement it

17. Hoe wordt uiteindelijk het besluit genomen welke kant opgegaan wordt?

    a. Hoeveel wegen duurzaamheidsaspecten mee in deze beslissing?

    b. Zitten hier ook embodied carbon overwegingen in?

6 Monitor and reassess the decision

18. Hoe vaak wordt het besluit reassessed?

    a. Wordt in deze reassess meer gekeken naar embodied carbon dan hiervoor?

    b. In welke fase speelt embodied carbon de grootste rol?

Business case parameters:

Nu zou ik graag willen inzoomen op de business case die gebruikt wordt om te zien of een project rendabel is. Ik heb voor mijn onderzoek een aantal business case parameters opgeschreven die volgens mijn literatuuronderzoek van belang zijn (geef de tabel hieronder op een a4tje aan de interviewde). Ik heb nog een aantal vragen over deze parameters.

Business case parameters		
Costs	**Income**	**Deal summary**
Gross m2 BVO	Lettable m2	Total project costs
Ratio	Income €/m2 (year)	Total investment value
Amount of units	Indexation	Profit
Construction costs	Income (/year) after index	Profit on costs
Additional costs	VAT	Profit on investment value
Land costs	Yield	Return of equity
Indexation	Value	Internal rate of return
Equity		
Loan		
Interest		
Contingency		

16. Wat is het doel van het maken van een business case?

17. Worden deze parameters door jullie allemaal gebruikt tijdens het maken van een business case voor een project?

18. Zijn er nog aanvullingen op de gegeven parameters die ik gemist heb?
    a. Zijn er duurzaamheidsparameters die niet in deze tabel staan?
        - Zo ja, welke zijn dit?

19. Zijn er nog embodied carbon parameters die nog niet genoemd zijn?

20. Is er nog iets wat we niet besproken hebben wat misschien van belang kan zijn voor mijn onderzoek?

Appendix 5 Exploratory interview protocol architect

Interview introductie:

Goedemorgen/Middag,

Hartelijk dank voor uw bereidheid om deel te nemen aan dit interview. Voordat ik begin, zal ik mezelf even voorstellen. Ik ben Tom, een student die de master Track Management in The Built Environment volgt aan de TU Delft. Op dit moment bevindt ik me in de laatste fase van mijn masteropleiding. Het uitvoeren van dit interview dient daarbij een belangrijk en leerzaam onderdeel voor het afstuderen. Ik kijk ernaar uit om uw waardevolle inzichten te verkrijgen en te gebruiken om onze kennis op het gebied van onderzoek te vergroten.

Graag zou ik uw toestemming vragen voor het opnemen van het interview, met als doel het vergemakkelijken van de transcriptie en het voeren van een vloeiend gesprek. De opnames zullen worden getranscribeerd en geanonimiseerd. Als u akkoord gaat met deze voorwaarden, wil ik u vragen het toestemmingsformulier te ondertekenen.

Starten met opname en opnieuw om toestemming vragen op opname

Om uw toestemming ook op de opname te hebben, herhaal ik wat ik net gezegd heb en zou ik u willen vragen ook voor de opname in uitgesproken woorden uw toestemming te verlenen. *Herhalen vorige alinea*

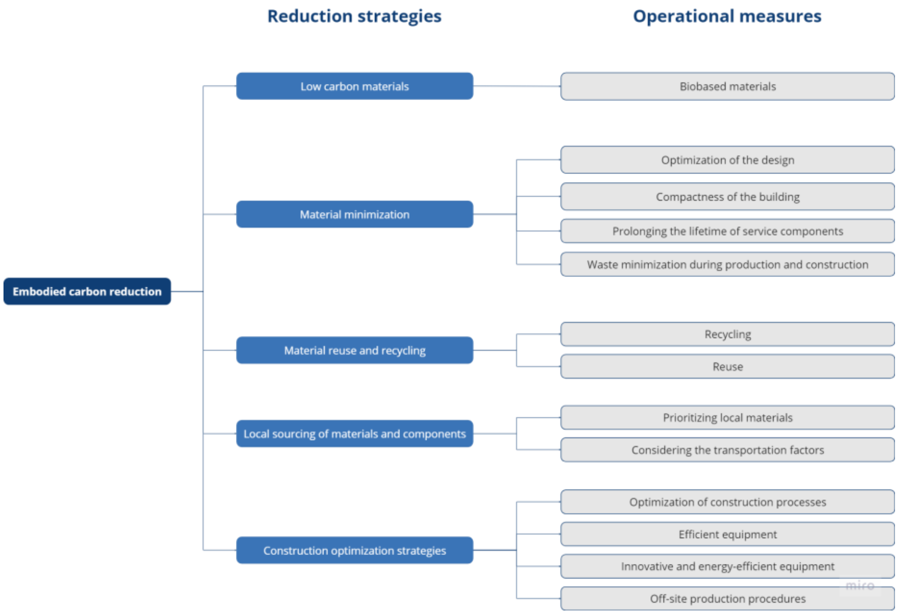
Algemene vragen:

1. Kunt u zichzelf kort voorstellen en iets vertellen over uw achtergrond?
    a. Wat is uw rol en wat zijn u verantwoordelijkheden in u bedrijf?

2. Wat weet u al over embodied carbon en de impact op de business case?

Embodied carbon reductie strategieën:

Hier zijn de 5 strategieën die ik via literatuuronderzoek gevonden heb om embodied carbon te verminderen in projecten. Ik zal de 5 strategieën uitleggen en daarna een aantal vragen stellen (geef de framework op een a4 aan de interviewde).



3. Zijn deze embodied carbon reductie strategieën bij u bekend?
    a. Zijn er nog strategieën die ik gemist heb tijdens mijn onderzoek?

4. Zijn de bijpassende operationele maatregelen bij u bekend?
    a. Zijn er maatregelen die hier nog missen?

Specifieke vragen:

5. Wat is uw ervaring met biobased materialen?
    a. Wat zijn de voor en nadelen van het gebruiken van deze materialen?

6. Hoe zorg je ervoor dat een project zo min mogelijk materialen gebruikt?
    a. Wat zijn de voor en nadelen die hieraan hangen?

7. Is het gebruik van materiaal hergebruik en recyclen een strategie die vaak wordt toegepast?
    a. Wat zijn specifieke operationele maatregelen voor het toepassen van deze strategie?
    b. Welke voor en nadelen zijn er voor het gebruiken van deze strategie?

8. Wordt het lokaal halen van de benodigde materialen vaak gebruikt als strategie?

    a. Zijn de transport factoren meegenomen in de afweging welk materiaal gekozen wordt?

9. Wordt er tijdens de bouw rekening gehouden met optimalisaties voor het verminderen van embodied carbon?

    a. Worden de afspraken die vooraf gemaakt zijn ook nageleefd door de bouw mensen?

10. Welke strategieën worden het meest toegepast in een project en waarom is dat?

a. Hebben deze strategieën ook het meeste invloed op het behalen van Paris Proof?

11. Welke strategieën worden het minste gebruikt en waarom?

    a. Zou dit in de toekomst kunnen veranderen? Om deze strategieën toch nog meer te benutten dan nu.

12. Zijn er verwachtingen dat in de toekomsten veranderingen in deze strategieën gaan komen?

    a. Zo ja? Welke veranderingen zijn dit en wat voor invloed hebben ze?

    b. Zo nee? Waarom is dit zo en gaan we Paris Proof wel halen met deze strategieën?

13. In hoeverre heeft welke stakeholder binnen een project invloed op welke strategieën er gebruikt worden?

14. Zijn er nog toevoegingen die we gemist hebben, die handig zijn om te weten?

Appendix 6 Exploratory interview protocol senior developer

Interview introductie:

Goedemorgen/Middag,

Hartelijk dank voor uw bereidheid om deel te nemen aan dit interview. Voordat ik begin, zal ik mezelf even voorstellen. Ik ben Tom, een student die de master Track Management in The Built Environment volgt aan de TU Delft. Op dit moment bevindt ik me in de laatste fase van mijn masteropleiding. Het uitvoeren van dit interview dient daarbij een belangrijk en leerzaam onderdeel voor het afstuderen. Ik kijk ernaar uit om uw waardevolle inzichten te verkrijgen en te gebruiken om onze kennis op het gebied van onderzoek te vergroten.

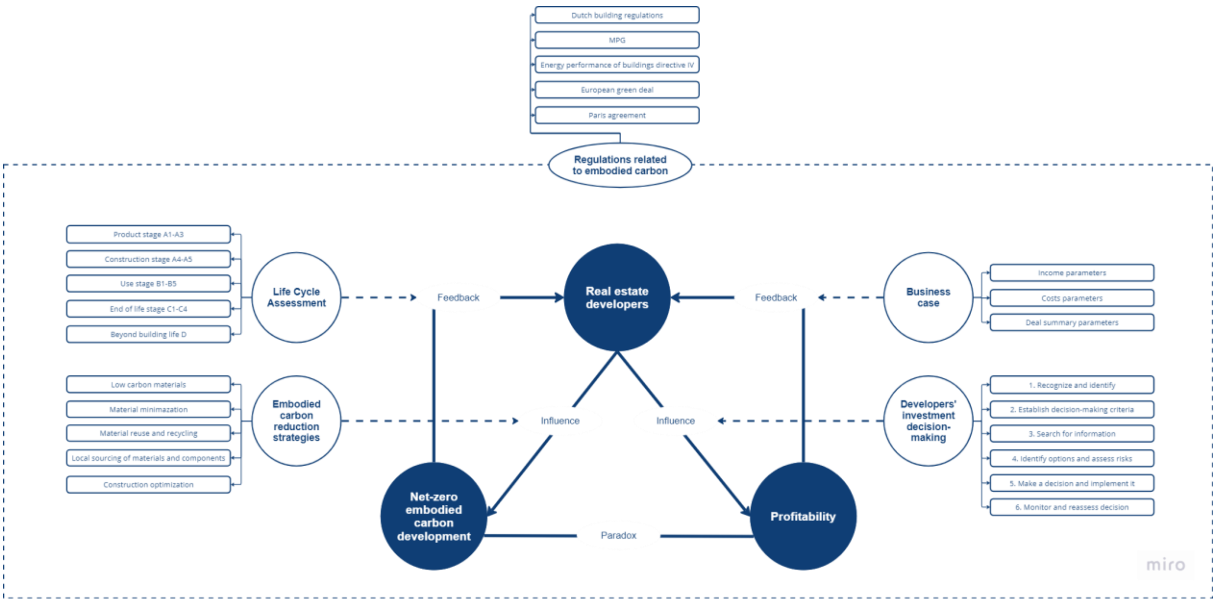
Graag zou ik uw toestemming vragen voor het opnemen van het interview, met als doel het vergemakkelijken van de transcriptie en het voeren van een vloeiend gesprek. De opnames zullen worden getranscribeerd en geanonimiseerd. Als u akkoord gaat met deze voorwaarden, wil ik u vragen het toestemmingsformulier te ondertekenen.

Starten met opname en opnieuw om toestemming vragen op opname

Om uw toestemming ook op de opname te hebben, herhaal ik wat ik net gezegd heb en zou ik u willen vragen ook voor de opname in uitgesproken woorden uw toestemming te verlenen. *Herhalen vorige alinea*

Impact van embodied carbon reductie strategieën op de business case:

Tijdens het theoretische onderzoek zijn er een aantal embodied carbon reductie strategieën naar voren gekomen die ik even zal toelichten. Deze strategieën hebben invloed op de business case van ontwikkelaars en hun beslissingsproces. Ook zijn er een aantal business case parameters gevonden in de theorie en getest bij een ontwikkelaar of deze kloppen. Nou ben ik benieuwd wat over het algemeen het idee van deze factoren is bij ontwikkelaars in de praktijk. Eerst zal ik wat algemenere vragen stellen waarna ik iets specifieker op dingen in ga.



Algemene vragen:

1. Kunt u zichzelf kort voorstellen en iets vertellen over uw achtergrond?
    a. Wat is uw rol en wat zijn u verantwoordelijkheden in u bedrijf?

2. Wat weet u al over embodied carbon en de impact op de business case?

Specifieke vragen:

3. Hoe worden deze reductie strategieën meegenomen binnen het bedrijf?

- Is dit project specifiek of zijn er ook algemene bedrijfscriteria over het toepassen van materiaal gebonden CO2 reductie?

4. Wat is de aanpak van het bedrijf bij het adopteren van nieuwe bouwtechnologieën en -praktijken die mogelijk de opgenomen koolstof kunnen verminderen? Zijn er specifieke innovaties die in de gaten gehouden of overweegt worden?

5. Tijdens de decision-making van een project zullen een aantal factoren zwaarder meewegen dan andere. Waar valt het behalen van een net-zero carbon gebouw in deze weging?

- Is het behalen van een goed rendement een grotere factor dan het behalen van net-zero?

6. Op welke manieren beïnvloeden de huidige regelgeving en markttrends het besluitvormingsproces van het bedrijf met betrekking tot de belichaamde koolstofreductie? Zijn er specifieke beleidsmaatregelen of markteisen die uw strategieën meer sturen dan andere?

7. Kunt u bespreken hoe het bedrijf met belanghebbenden (investeerders, klanten, eindgebruikers) omgaat met het onderwerp materiaal gebonden koolstofreductie? Hoe bepalen hun verwachtingen of eisen uw strategieën?

- Zijn er specifieke stakeholders die meer invloed hebben dan andere? Welke zijn dit en waarom?

8. In de theorie die ik gevonden heb staat dat het toepassen van deze reductie strategieën resulteert in hogere bouwkosten/investeringen maar aan de andere hand ook resulteert in hogere huur/koopopbrengsten en lagere operationele kosten en waardevermindering. Hoe denkt u hierover?

9. Wat moet er veranderen om de reductie strategieën toe te kunnen passen zonder dat het rendement van de ontwikkelaar hieraan ten onder gaat?

    - Heeft de carbon prijs hier nog een invloed in? Want als de carbon prijs stijgt zullen materialen zoals beton duurder worden en materialen zoals hout die co2 opslaan goedkoper worden.

10. Is de zoektocht naar de balans tussen de reductie strategieën en de business case iets waar het bedrijf mee bezig is en in wat voor maten zullen dingen veranderen binnen het bedrijf om deze balans recht te trekken?

11. Zijn er nog aspecten die van waarde kunnen zijn voor mijn onderzoek die we nog niet besproken hebben?

Appendix 7 Case interview protocol developers

The interview protocol is written in Dutch at the request of the interviewees. The interview protocol shown here is the basis that is used and changed according to the knowledge already gathered through other interviews and document analysis.

Interview protocol

Goedemorgen/Middag,

Hartelijk dank voor uw bereidheid om deel te nemen aan dit interview. Voordat ik begin, zal ik mezelf even voorstellen. Ik ben Tom, een student die de master Track Management in The Built Environment volgt aan de TU Delft. Op dit moment bevindt ik me in de laatste fase van mijn masteropleiding. Het uitvoeren van dit interview dient daarbij een belangrijk en leerzaam onderdeel voor het afstuderen. Ik kijk ernaar uit om uw waardevolle inzichten te verkrijgen en te gebruiken om onze kennis op het gebied van onderzoek te vergroten.

Ik zal nog een keer mijn onderzoeksvraag vertellen om deze altijd in het achterhoofd te houden tijdens dit onderzoek: *"Hoe kunnen ontwikkelaars strategieën voor het verminderen van embodied carbon implementeren terwijl ze de winstgevendheid waarborgen?"*

Graag zou ik uw toestemming vragen voor het opnemen van het interview, met als doel het vergemakkelijken van de transcriptie en het voeren van een vloeiend gesprek. De opnames zullen worden getranscribeerd en geanonimiseerd. Als u akkoord gaat met deze voorwaarden, wil ik u vragen het toestemmingsformulier te ondertekenen.

Starten met opname en opnieuw om toestemming vragen op opname

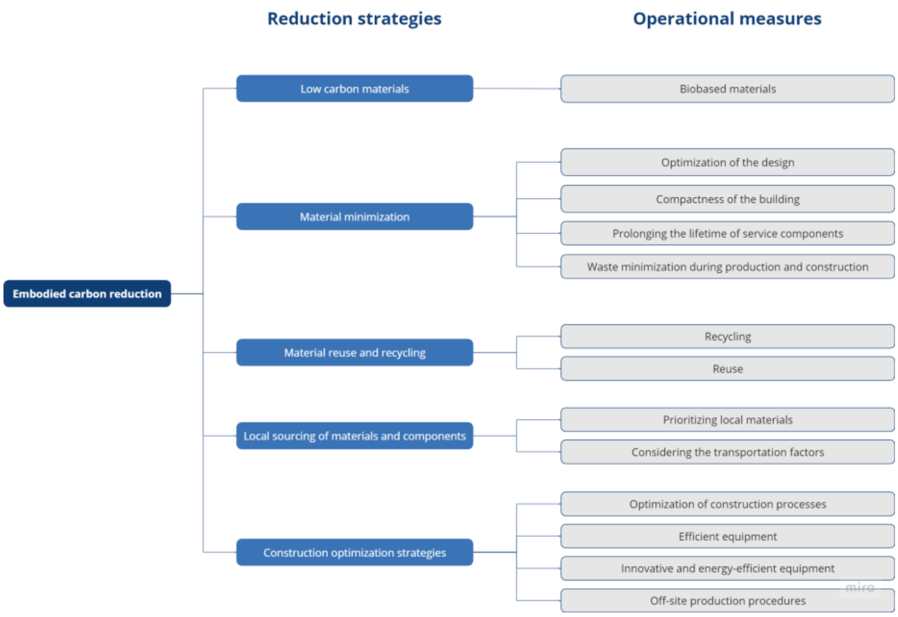
Om uw toestemming ook op de opname te hebben, herhaal ik wat ik net gezegd heb en zou ik u willen vragen ook voor de opname in uitgesproken woorden uw toestemming te verlenen. *Herhalen vorige alinea*

Deel 1 Algemene vragen:

1. Kunt u zichzelf kort voorstellen en iets vertellen over uw achtergrond? En wat is uw rol en verantwoordelijkheden binnen uw bedrijf?
    a. Hoe zit het bedrijf in elkaar en wat doet het precies?
2. Hoe bent u betrokken geweest bij het project?
3. Kan u in het kort toelichten hoe jullie in het project staan?
    a. Eigen vermogen? Gedelegeerd?
    b. Met of zonder lening?
4. Zou u kort wat kunnen toelichten over het project?
5. Wat was het initiële hoofddoel van het project?
    - Was het verminderen van CO_2 uitstoot een speerpunt?
6. Wat weet u al over materiaal gebonden CO_2 uitstoot en de impact op het rendement?

Deel 2 Impact op rendement:

IK – Uitleg reductie strategieën en impact op business case parameters: Nu zou ik graag willen inzoomen op de reductie strategieën die zijn toegepast en de business case die gebruikt wordt om te zien of een project rendabel is. Ik heb voor mijn onderzoek een aantal strategieën gevonden en business case parameters opgeschreven die volgens mijn literatuuronderzoek van belang zijn (geef de figuren hieronder op een a4tje aan de interviewde). Ik heb nog een aantal vragen over de impact van de reductie strategieën op deze parameters.



Business case parameters		
Costs	**Income**	**Deal summary**
Gross m2 BVO	Lettable m2	Total project costs
Ratio	Income €/m2 (year)	Total investment value
Amount of units	Indexation	Profit
Construction costs	Income (/year) after index	Profit on costs
Additional costs	VAT	Profit on investment value
Land costs	Yield	Return of equity
Indexation	Value	Internal rate of return
Equity		
Loan		
Interest		
Contingency		

1. Welke van deze reductie strategieën hebben jullie gebruikt?
   a. Hoe is hierop gestuurd?

2. Hoe zijn jullie tot deze strategieën gekomen?

3. Zijn er nog andere strategieën die toegepast zijn die hier niet opstaan?

4. Hebben de strategieën over het algemeen invloed gehad op de bouwkosten of aankoop kosten, bouwtijd en BVO/GBO verhouding of andere business case parameters?

IK - Zelf nalopen of er nog andere strategieën gebruik zijn

Low-carbon materials:

1. Welke low-carbon materialen worden er binnen het project gebruikt?
    a. Hoe is dit gekozen?
        i. Is er vanuit de tender/initiatie fase specifiek voor gekozen?
    b. Waarom gekozen voor specifiek deze materialen? Wat is de impact hiervan geweest?
    c. Worden er ook nog andere materialen gebruiken die minder CO2 uitstoten dan traditioneel materialen?
    d. Was het bouwen in hout en de andere reductie materialen duurder en zo ja hoeveel %?
    e. Heeft het impact gehad op de bouwkosten, bouwtijd of GBO/BVO verhouding of een andere business case parameters?

Material minimization:

1. Welke materialisatie verminderingen zijn er toegepast bij dit project?
    a. Is dit al vanuit de tender/initiatie fase gekozen?
        i. Hoe is dit gedaan en wat voor invloed heeft dit gehad?
        ii. Zijn er nog op andere vlakken materiaalbesparingen gedaan?
    b. Focussen jullie je ook op het compact bouwen?
        i. Zo ja? Wat voor invloed heeft dit gehad op de materiaal gebruik?
            1. Maar ook GO/BVO verhouding?
            2. Invloed hiervan op opbrengsten, aankoopwaarde?
    c. Impact gehad op aankoop/bouwkosten, Bouwtijd of GBO/BVO verhouding?

2. Is er voor de rest nog gekeken naar het kijken naar het wat voor type installaties en vervangingstermijn, misschien zo ontwerpen dat je minder installaties nodig hebt of het verminderen van afval tijdens de productie en constructie?

Material Reuse and Recycling:

1. Zijn er materialen gebruikt die hergebruikt of gerecycled zijn?
    a. Heeft dit invloed gehad op de business case?

2. Zijn er materialen gebruikt die na de bouw hergebruikt of gerecycled zouden kunnen worden?
    a. Heeft dit nog op een manier invloed op de business case en welke parameter precies?

Local sourcing of materials:

1. Waar komt het grootse gedeelte van de materialen vandaag?
    a. Zit er verschil in kosten bij de afstand waar materialen vandaan moeten komen?

2. Is er nagedacht over de manier van transportatie naar de bouw toe?
    a. Wat voor invloed heeft dit gehad op CO_2 uitstoot?
    b. Is er gestuurd om op deze manier CO_2 uitstoot te verminderen?
    c. Wat heeft dit voor gevolg gehad op de business case?

Constuction optimazation

1. Wat voor soort bouwmethode is er gebruikt?
    a. Is daarbij gekeken naar verminderen van CO_2 uitstoot.
    b. Heeft het invloed gehad op de business case?

2. Een van de strategieën is ook het optimaliseren van de constructie activiteiten, is hiernaar gekeken?
    a. Wat voor invloed heeft dit gehad op zowel het reduceren als de business case?

3. Is er gebruikt gemaakt van optimale constructie equipment tijdens de bouw?
    a. Zo ja? Wat voor positief effect heeft dit gehad op het reduceren van embodied carbon?
    b. Wat voor invloed heeft het op de business case gehad?

4. Zijn er ook energie efficiënte machines gebruikt tijdens de bouw die ook voor reductie in CO_2 uitstoot zorgen?
    a. Wat betekende dit voor de bouwkosten en bouwtijd?

Deel 3 Overige vragen:

1. Ik zag dat er CO_2 wordt opgeslagen, wordt hier nog iets mee gedaan?

2. Er is binnen dit project gebruik gemaakt van carbon offsetting?
    - Wat waren de kosten hiervan?

3. Daarnaast heb je nog carbon pricing and carbon taxing, wat is u mening hierover?

Deel 3 Impact op beslissingsproces

IK – ik zal starten met deel 2, hierin zal ik wat vragen gaan stellen over het algemene beslissingsproces die jullie doorlopen. Dit zal ik doen aan de hand van 6 stappen. Ik zal per stap eerst een korte toelichting geven en daarna hier wat vragen stellen over hoe jullie dit doen en of dit veranderd wanneer het verlagen van embodied carbon wordt meegenomen.

Steps:	Explanation:
7. Recognize and identify	Ten eerste moet er erkenning zijn dat een project op de markt is en dat de ontwikkelaar geïnteresseerd is in een investering.
8. Establish decision-making criteria	Zowel organisatie- als projectdoelstellingen spelen een belangrijke rol bij een investeringsbeslissing; deze criteria kunnen standaarden zijn voor alle projecten of per project.
9. Search for information	Het zoeken naar informatie wordt als voorwaardelijk beschouwd en is nodig om verschillende varianten te kunnen maken.
10. Identify options and assess risk	Verschillende varianten moeten gemaakt worden waarna doormiddel van een business case een haalbaarheidstoets zal worden gedaan.
11. Make a decision and implement it	De verschillende opties voor de ontwikkeling worden verkend en geanalyseerd. Waarna een keuze gemaakt moet worden of er doorgegaan of gestopt wordt.
12. Monitor and reassess the decision	Als er door wordt gegaan zal de keuze steeds opnieuw nagelopen moeten worden met de business case ernaast om de juiste keuzes te blijven maken.

Stap 1: Recognize and identify

Toelichting:

19. Hoe vinden jullie over het algemeen potentiële projecten?

20. Hoe beslis je dat je als ontwikkelaar in eerste instantie geïnteresseerd bent in een project?
    a. Worden tijdens de recognition stap over het algemeen duurzaamheidsaspecten zoals embodied carbon meegenomen?

21. Hoe is deze stap in dit specifieke project genomen?
    a. Verschilt dit met wat jullie in het algemeen tijdens deze stap doen, door het streven naar reductie van CO_2?
    b. Wat is het verschil?

Stap 2: Establish decision-making criteria

Toelichting:

4. Hebben jullie bepaalde algemene decision-making criteria die jullie volgen als bedrijf?

   a. Hoe worden deze criteria opgeschreven en bijgehouden?

   b. Wordt er binnen deze criteria ook iets gezegd over duurzaamheid?

   c. En wordt hier embodied carbon in meegenomen?

5. Hoe zijn de decision-making criteria in dit specifieke project neergelegd?
    a. Verschilt dit met wat jullie in het algemeen tijdens deze stap doen, door het streven naar reductie van CO2?
    b. Wat is jet verschil?

Stap 3: Search for information

Toelichting:

6. Hoe wordt de informatie voor de potentiële projecten over het algemeen verzameld?
    a. Zoeken jullie ook naar informatie over duurzaamheid tijdens deze stap?
    b. En zit hier dan ook embodied carbon informatie bij?
7. Zit er verschil tussen hoe jullie over het algemeen de informatie zoeken en hoe het bij dit project specifiek is verlopen?
    a. Komt dit mede door de reductie strategieën die zijn toegepast?
    b. Wat is het verschil dan?

Stap 4: Identify options and assess risk

Toelichting:

8. Hoe vertalen jullie over het algemeen de gevonden informatie in de juiste varianten die uitgezocht gaan worden?
    a. Nemen jullie in de varianten duurzaamheidsaspecten mee?
    b. Zit in die duurzaamheidsaspecten ook embodied carbon?
9. Is dit tijdens dit specifieke project anders gegaan en waardoor komt dit?
    a. Heeft het meenemen van CO2 reductie een groot verschil gegeven?

10. Kunt u de financiële modellen beschrijven die u gebruikt om potentiële ontwikkelingsprojecten te evalueren?
    a. Is dit model hetzelfde als er CO2 reductie strategieën worden toegepast?
11. Hoe balanceert u risico en rendement bij uw beleggingsbeslissingen?
    a. Veranderd er iets aan de balans tussen risico en rendement wanneer embodied carbon wordt meegenomen?

Stap 5: Make a decision and implement it

Toelichting:

12. Hoe wordt uiteindelijk het besluit genomen welke kant opgegaan wordt?

    a. Hoeveel wegen duurzaamheidsaspecten over het algemeen mee in deze beslissing?

13. Hoe zit het bij dit project specifiek?
    a. Is er iets veranderd in deze stap door de reductie strategieën?

Stap 6: Monitor and reassess the decision

Toelichting:

14. Hoe vaak wordt het besluit reassessed?
15. Word dit specifieke project vaker reassessed dan over het algemeen?
    a. Komt dit door de reductie strategieën?

Afsluiting: Hartelijk dank voor uw tijd en inzichten. Zijn er nog andere opmerkingen of ervaringen die u wilt delen met betrekking tot de vermindering van de ingebedde koolstof in gebouwen?

Appendix 8 Case interview protocol architects

The interview protocol is written in Dutch at the request of the interviewees. The interview protocol shown here is the basis that is used and changed according to the knowledge already gathered through other interviews and document analysis.

Interview protocol

Goedemorgen/Middag,

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Graag zou ik uw toestemming vragen voor het opnemen van het interview, met als doel het vergemakkelijken van de transcriptie en het voeren van een vloeiend gesprek. De opnames zullen worden getranscribeerd en geanonimiseerd. Als u akkoord gaat met deze voorwaarden, wil ik u vragen het toestemmingsformulier te ondertekenen.

Starten met opname en opnieuw om toestemming vragen op opname

Om uw toestemming ook op de opname te hebben, herhaal ik wat ik net gezegd heb en zou ik u willen vragen ook voor de opname in uitgesproken woorden uw toestemming te verlenen. *Herhalen vorige alinea*

Deel 1 Algemene vragen:

1. Kunt u zichzelf kort voorstellen en iets vertellen over uw achtergrond en uw rol binnen de bouwsector beschrijven?

2. Hoe bent u betrokken geweest bij het project?

3. Zou u wat kunnen toelichten over het project en hoe dit project tot stand is gekomen?

    - Bouwtijd? Aankoopkosten? Bouwmethode? Bouwprijzen?

4. Wat was het initiële hoofddoel van het project?

    - Was het verminderen van CO_2 uitstoot een speerpunt?

5. Zou je wat kunnen toelichten over de algemene duurzaamheid van het project?

    - Welke MPG score heeft het behaald?

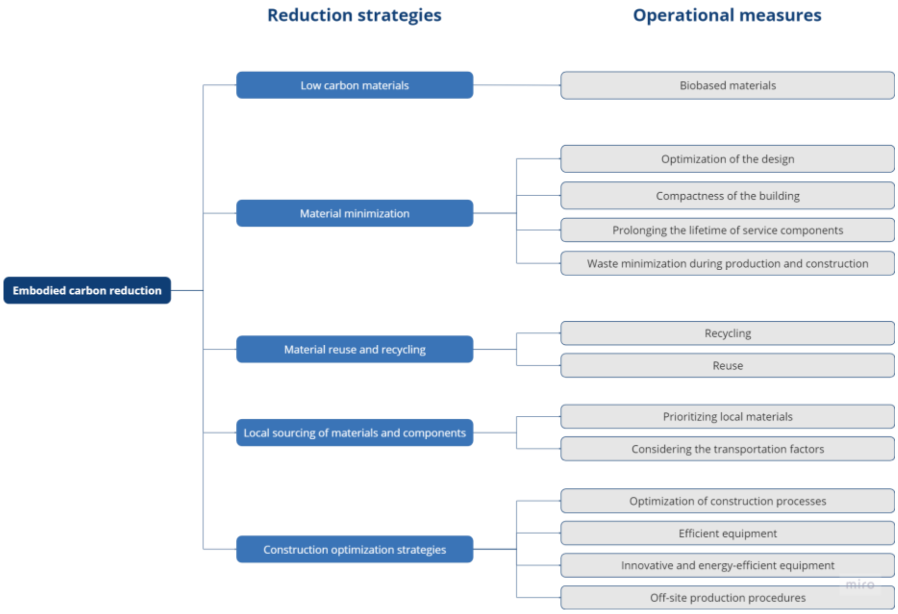
    - Hoeveel CO_2 per m^2?

    - Welke elementen hebben het meeste invloed op deze score gehad?

    - Is het mogelijk om het MPG score rapport te delen?

Deel 2 Reductie strategieën:

IK - Uitleg reductie strategieën: ik ga nu even in het kort alle reductie strategieën doorlopen, ik zal deze even 1 voor 1 toelichten. Dan stel ik wat algemene vragen over het verlagen van de materiaal gebonden CO2 uit en daarna wil ik graag elke strategie met jullie doorlopen.



5. Welke strategieën zijn er gebruikt om het materiaal gebonden CO2 te verlagen in het project?

6. Waarom is er gekozen voor deze manieren?

7. Hoe zijn jullie tot deze strategieën gekomen?

8. Is er nagedacht over andere strategieën?

IK - Zelf nalopen of er nog andere strategieën gebruik zijn

Low-carbon materials:

2. Welke low-carbon materialen worden er binnen het project gebruikt?
   a. Waarom gekozen voor specifiek deze materialen? Wat is de impact hiervan geweest?
   b. Worden er ook nog andere materialen gebruiken die minder CO2 uitstoten dan traditioneel materialen?
   c. Zijn deze keuzes in de eerste fase al gemaakt of kwamen ze later aan bod en wat had dit voor gevolg?

Material minimization:

3. Welke materialisatie verminderingen zijn er toegepast bij dit project?
    a. Is dit al vanuit de tender/initiatie fase gekozen?
        i. Hoe is dit gedaan en wat voor invloed heeft dit gehad?
        ii. Zijn er nog op andere vlakken materiaalbesparingen gedaan?
    b. Focussen jullie je ook op het compact bouwen?
        i. Zo ja? Wat voor invloed heeft dit gehad op de materiaal gebruik? Maar ook GO/BVO verhouding?

4. Is er voor de rest nog gekeken naar het kijken naar het wat voor type installaties en vervangingstermijn, misschien zo ontwerpen dat je minder installaties nodig hebt?

5. En hoe zit het met het verminderen van afval tijdens de productie en constructie?

Material Reuse and Recycling:

3. Zijn er materialen gebruikt die hergebruikt of gerecycled zijn?
    a. Heeft dit invloed gehad op het behalen van Paris Proof?

4. Zijn er materialen gebruikt die na de bouw hergebruikt of gerecycled zouden kunnen worden?
    a. Heeft dit nog op een manier invloed op certificaten en het reduceren van CO2?

Local sourcing of materials:

3. Waar komt het grootse gedeelte van de materialen vandaag?
    a. Zit er een groot verschil in waar je de materialen vandaan haalt op het reduceren van CO2 en het behalen van certificaten?

4. Is er nagedacht over de manier van transportatie naar de bouw toe?
    a. Wat voor invloed heeft dit gehad op CO2 uitstoot?
    b. Is er gestuurd om op deze manier CO2 uitstoot te verminderen?

Constuction optimazation

5. Wat voor soort bouwmethode is er gebruikt?
    a. Is daarbij gekeken naar verminderen van CO2 uitstoot.

6. Een van de strategieën is ook het optimaliseren van de constructie activiteiten, is hiernaar gekeken?
    a. Wat voor invloed heeft dit gehad op zowel het reduceren als het behalen van certificaten en een lage MPG score?

7. Is er gebruikt gemaakt van optimale constructie equipment tijdens de bouw?
    a. Zo ja? Wat voor positief effect heeft dit gehad op het reduceren van embodied carbon?

8. Zijn er ook energie efficiënte machines gebruikt tijdens de bouw die ook voor reductie in CO_2 uitstoot zorgen?

Deel 3 Overige vragen:

4. Ik zag dat er CO_2 wordt opgeslagen, wordt hier nog iets mee gedaan?

5. Is er binnen dit project gebruik gemaakt van carbon offsetting?
   - Wat waren de kosten hiervan?

6. Daarnaast heb je nog carbon pricing and carbon taxing, wat is u mening hierover?

Afsluiting: Hartelijk dank voor uw tijd en inzichten. Zijn er nog andere opmerkingen of ervaringen die u wilt delen met betrekking tot de vermindering van de ingebedde koolstof in gebouwen?

Appendix 9 Expert panel protocol

The expert panel protocol is written in Dutch at the request of the participants.

Expert panel protocol

Goedemorgen/Middag,

Hartelijk dank voor uw bereidheid om deel te nemen aan deze expert panel. Voordat ik begin, zal ik mezelf even voorstellen. Ik ben Tom, een student die de master Track Management in The Built Environment volgt aan de TU Delft. Op dit moment bevindt ik me in de laatste fase van mijn masteropleiding. Het uitvoeren van deze expert panel dient daarbij een belangrijk en leerzaam onderdeel voor het afstuderen. Ik kijk ernaar uit om uw waardevolle inzichten te verkrijgen en te gebruiken om onze kennis op het gebied van onderzoek te vergroten.

Graag zou ik uw toestemming vragen voor het opnemen van de expert panel, met als doel het vergemakkelijken van de transcriptie en het voeren van een vloeiend gesprek. De opnames zullen worden getranscribeerd en geanonimiseerd. Als u akkoord gaat met deze voorwaarden, wil ik u vragen het toestemmingsformulier te ondertekenen.

Starten met opname en opnieuw om toestemming vragen op opname

Om uw toestemming ook op de opname te hebben, herhaal ik wat ik net gezegd heb en zou ik u willen vragen ook voor de opname in uitgesproken woorden uw toestemming te verlenen. *Herhalen vorige alinea*

Inleiding

Tijdens mijn onderzoek ben ik een aantal bevindingen tegengekomen die ontwikkelaars kunnen toepassen om de paradox tussen winstgevenheid en materiaalgebonden CO2 vermindering te managen. Deze bevindingen wil ik graag met jullie bespreken en bediscussieren om mijn onderzoek te valideren, vooral kijkend naar de toepassing in de praktijk.

Bespreking van de implementatie van de volgende belangrijkste bevindingen:

- Holistische duurzaamheidsplanning op gebiedsniveau
- Innovatieve bouwmethoden
- Betrokkenheid van belanghebbenden
- Balanceren van strategieën tegen langetermijnvoordelen
- Hybride bouwoplossingen
- Deelname aan koolstofkredietmarkten
- Onderhandelen over verbeterde financieringsvoorwaarden
- Benutten van versnelde houtbouw
- Uitgebreide database voor materialen
- Gestandaardiseerd CO2-trackingtool
- Regelgevings- en beleidskaders

- Investeren in kennis en vaardigheden
- Marktvraag naar duurzame woonruimtes
- Implementatie van koolstofbeprijzing
- Subsidies voor duurzame praktijken
- Lokale productie van duurzame materialen
- Optimalisering van duurzame toeleveringsketens

Conclusie: Samenvatten van de belangrijkste punten, verzamelen van laatste gedachten en bespreken van de volgende stappen voor het integreren van feedback in de scriptie.