Embodied carbon: the hidden challenge for real estate developers

Achieving net-zero carbon building ambitions by steering on including embodied carbon during the early design process

Colophon

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Preface

Throughout my time as a student at TU Delft, sustainability has always played a huge role in learning about the built environment. The main lesson I have learned is that sustainability has everything to do with balance. When paying too much attention or enjoying the benefits of one aspect, other aspects get neglected and deteriorate. For that reason, I always find it important to zoom out, look at the bigger picture and divide my energy accordingly.

In recent years, the primary focus of the decarbonization effort in the building and construction industry has been on lowering operational carbon, without taking into account the embodied carbon impact of these reduction measures. For that reason, I decided to distribute my energy toward an underexposed topic that is gaining attention in both the scientific community and the building and construction industry: embodied carbon.

The opportunity to conduct my research at one of the frontrunners in real estate development (EDGE), provided the chance to talk to a lot of knowledgeable people within the industry. Conducting the interviews is what I enjoyed most during the process and I truly appreciate the time everyone took to discuss this complex topic with me.

I would like to express my gratitude to my supervisors Paul Chan and Andy van den Dobbelsteen for guiding me in the right direction and giving me trust. I would also like to thank EDGE, and in particular Constantijn Berning for the practical lessons during our weekly meeting and the freedom I enjoyed while conducting my research. Although they all have very busy schedules, I never felt like they did not have the time to help me.

Hopefully, this thesis will reach developers and accelerate efforts towards net-zero carbon ambitions.

Sincerely,

Rowin Teunissen

Amsterdam

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“If you can’t measure it, you can’t change it “

- Peter Drucker -

Abstract

Purpose – Given the urgent need to decarbonize the building and construction industry to prevent a catastrophic climate breakdown. The United Nations has called for action from industry leaders to drastically decrease their carbon footprint, and bring it to zero by 2050 at the latest. Efforts to decrease operational carbon emissions associated with energy used to light, heat, cool, and power buildings are striving considerably. Attempts to minimize embodied carbon emissions, on the other hand, are falling behind. This has resulted in an increase in both the relative and absolute contribution of embodied carbon. The importance of the early design process concerning embodied carbon reduction has repeatedly been emphasized throughout the literature. Change in the early design process is required to reduce embodied carbon. The purpose of this research is to determine how real estate developers can steer on including embodied carbon during the early design process, to achieve net-zero carbon building ambitions.

Research question –

How can real estate developers steer on including embodied carbon during the early design process to achieve net-zero carbon building ambitions?

Methodology – Qualitative research methods were used to answer the research question. Following a literature review to establish the theoretical background, 'Research through design' was used during the empirical research. Semi-structured interviews with real estate developers and design team members were conducted to Identify the relevant actors within the early design process and the activities that need to be completed to steer on embodied carbon. Furthermore, guidelines for real estate developers were developed to assist in achieving net-zero carbon building ambitions. The findings are used as input for the creation of a prototype that can be used by real estate developers. Finally, this prototype was validated and improved through two focus groups.

Keywords – Embodied carbon; net-zero carbon building; early design process; carbon footprint; Life cycle assessment; real estate developersd

Executive summary

Introduction

To reach the goals set out in the Paris Agreement, there is an immediate obligation to reduce carbon emissions caused by the building and construction industry. Developing net-zero carbon buildings (buildings were in addition to net-zero operational, embodied carbon across the building life cycle is reduced to a level that is consistent with reaching net-zero carbon at a sectoral level), is a promising approach to reduce carbon emissions. Recent studies show the growing relative and absolute contribution of embodied carbon in buildings. While the reduction of operational carbon in buildings is striving considerably, the reduction of embodied carbon is falling behind.

Good design practices and appropriate design decisions have been identified as crucial strategies for mitigating embodied carbon. Current practice typically involves assessing embodied carbon late in the design process, when it is too late to significantly alter the design. The main barriers are the availability and accessibility of detailed data and the appropriateness of tools, methods, and guidelines for early design process use. Existing studies on embodied carbon in the early design process often overlook the perspective of a crucial actor, the real estate developer. As a client and decision-makers during the early design process, real estate developers play a crucial role. However, it is unclear for real estate developers how to include embodied carbon during the early design process.

Research objectives

This research aims to bridge the research gap by providing guidance for real estate developers. The objectives include exploring opportunities and challenges in reaching net-zero carbon building ambitions, understanding criteria and assumptions related to embodied carbon, and identifying key actors and activities. This thesis delivers early design process guidelines on how to steer on including embodied carbon. Furthermore, a prototype that transforms these guidelines into a visual representation and learning tool is created.

Methodology

Qualitative research methods were used to answer the research questions. ‘Research through design’ was used during the empirical research, through the creation of a prototype. Semi-structured interviews with real estate developers and design team members of the ‘Jaarbeursplein’ project were conducted to understand the tensions and contradictions in the current practice of including embodied carbon. To validate the prototype and findings two focus groups were consulted.

Key findings

The findings indicate that in steering on including embodied carbon during the early design process, it is crucial to set an embodied carbon target (KgCO2e/m2) for the building. Furthermore, by appointing one of the design team members as the carbon assessor and gradually assessing the embodied carbon footprint throughout the design process, design decisions can be made based on estimates. Involving suppliers and urban minders early in the design process can increase the amount the detailed information required for the carbon assessment. However, the number of suppliers and urban miners that are collaborated with should be considered carefully. Dedicating specific design meetings to reducing the embodied carbon impact, can help to increase knowledge and create a common language within the design team. Additionally, existing standards and regulations should be challenged, to decrease the uncertainty surrounding them.

Discussion

This research addresses the uncertainties surrounding net-zero carbon buildings and embodied carbon. A surprising actor, the cost consultant, could be appointed as the carbon assessor to increase embodied carbon accounting adoption, contradicting previous research. The developer's responsibility for embodied carbon impact over the building life cycle remains debatable. Nevertheless, gradual assessment of embodied carbon during early design proved to be highly desirable, aligning with previous studies. New insights into the early involvement of suppliers and urban miners imply that these actors will play an increasingly essential role in achieving net-zero carbon building ambitions.

Recommendations

Further research is required to investigate the role that investors play in the decisions making process regarding embodied carbon and the way they value net-zero carbon buildings. Furthermore, a study into the requirements for a separate “net-zero carbon building” label or classification could help to create more clarity surrounding its definition and relationship to the existing sustainable building labels. In addition, the insufficiency of current carbon offset prices as an incentive for real estate developers necessitates a study into the stage at which the financial burdens of carbon offsetting impact decision-making.

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Chapter 1

Introduction

/01 Introduction

1.1 Research context

The consequences of climate change and its already-occurring effects are forcing an intense urgency for reducing carbon emissions. To prevent a catastrophic climate breakdown, the average global temperature increase should be contained to well below 2°C and preferably to 1.5°C compared to pre-industrial levels (IPCC, 2019). There is a scientific consensus that carbon emissions are directly linked to global temperature rise. Therefore, during the COP21 in Paris binding agreements were made to ensure the reduction of all global carbon emissions to zero by 2050. According to the United Nations Environment Program, the building and construction sector account for a staggering 37 percent of all carbon emissions in the world (Figure 1.1). For this reason, they consider the building and construction sector as a primary target for carbon emissions mitigation efforts and call for action from industry leaders and actors.

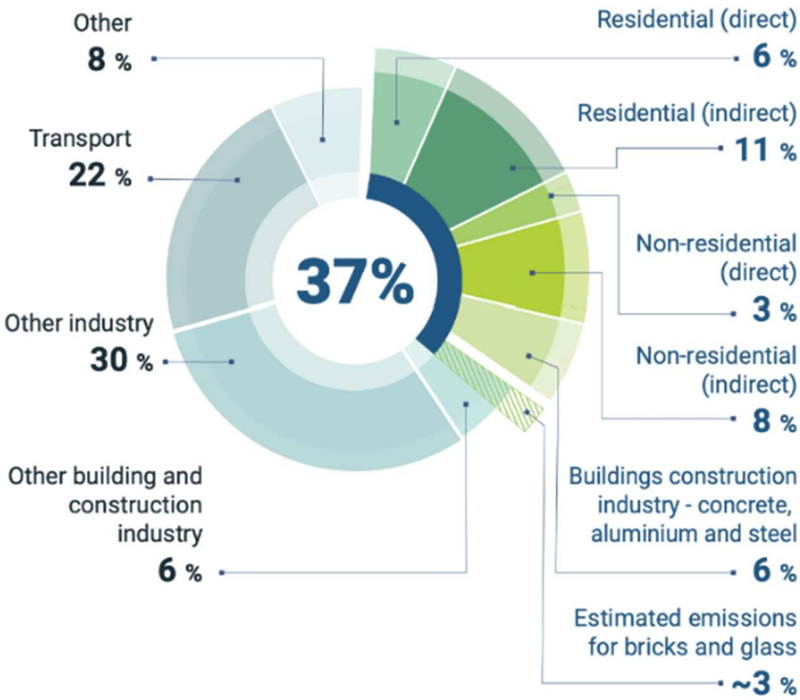


Figure 1.1: Global share of buildings and construction operational and embodied CO2 emissions 2021 (UNEP, 2022)

This call to action has been heard, and an increasing number of industry leaders are committing to drastically decreasing their carbon emissions (World Green Building Council, 2019). Aligning with the ambitions set out in the Paris Agreement to reach net-zero carbon emissions across all activities in the building and construction industry. Achieving net-zero carbon is the process of ensuring that a company, on average, puts no carbon emissions into the atmosphere (World Economic Forum & JLL, 2021). Industry pioneers (investors, builders, and real estate developers) are calculating the carbon footprint of their companies and buildings, developing roadmaps, and setting milestones to achieve the net-zero carbon goal. Reducing their carbon emissions step-by-step, these frontrunners will pave the way for the rest of the building and construction sector to follow.

While the carbon footprint calculation of a company is relatively easy (World Economic Forum & JLL, 2021), calculating the carbon footprint of a building project is often more difficult. The carbon footprint of a building can be divided into two main categories; ***I) 'operational carbon'***; carbon emissions associated with energy used to light, heat, cool, and power a building, and II) ***'embodied carbon'***; carbon emissions occurring during the extraction of raw materials, manufacturing, transportation, construction, maintenance and end-of-life phases of a building (World Green Building Council, 2017). Together, these emissions form the whole-life carbon emissions of a building.

1.2 Review of previous studies

1.2.1 The growing importance of embodied carbon

So far, efforts to reduce building-related carbon emissions have primarily focused on improving energy efficiency to reduce operational energy demand and associated operational carbon (Röck et al., 2020). These reduction approaches are striving considerably and led to the development of highly energy-efficient buildings such as nearly energy-zero buildings (NEZB) and energy-zero buildings (EZB) (Ohene et al., 2022).

As it is widely assumed that the share of operational carbon is far greater than embodied carbon, considerable efforts have been devoted to reducing the operational carbon of buildings. While this assumption might have been true years ago, recent studies show that the average share of embodied carbon in buildings is rising (Ibn-Mohammed et al., 2013; Röck et al., 2020). Innovations and technological advances in the area of energy efficiency have led to an increase in material use and energy demand for their production, which has increased both the relative and absolute contribution of embodied carbon (Ibn-Mohammed et al., 2013; Pomponi & Moncaster, 2016; Röck et al., 2020).

According to Pomponi, Moncaster, & de Wolf (2018), an accurate understanding of carbon estimates is a crucial starting point in the carbon debate. The most developed and globally recognized standardized method of environmental impact assessment in the building sector is; ***life cycle assessment* (LCA)** (Amiri et al., 2021). LCA aims to measure and analyze the environmental impact related to the production, transport, use, and end-of-life of a particular building element, component or the whole building. To assist in describing the environmental impact of a building, its life cycle is split into stages and modules as defined by EN 15978 (Figure 1.2).

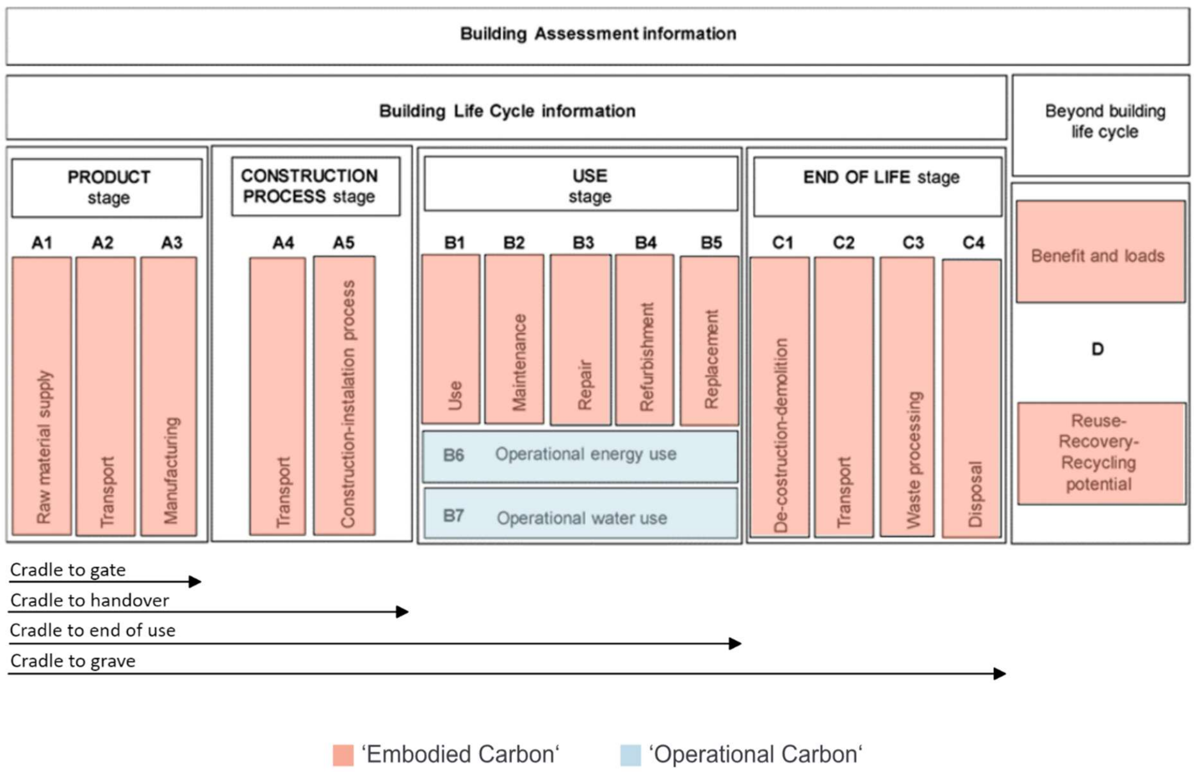


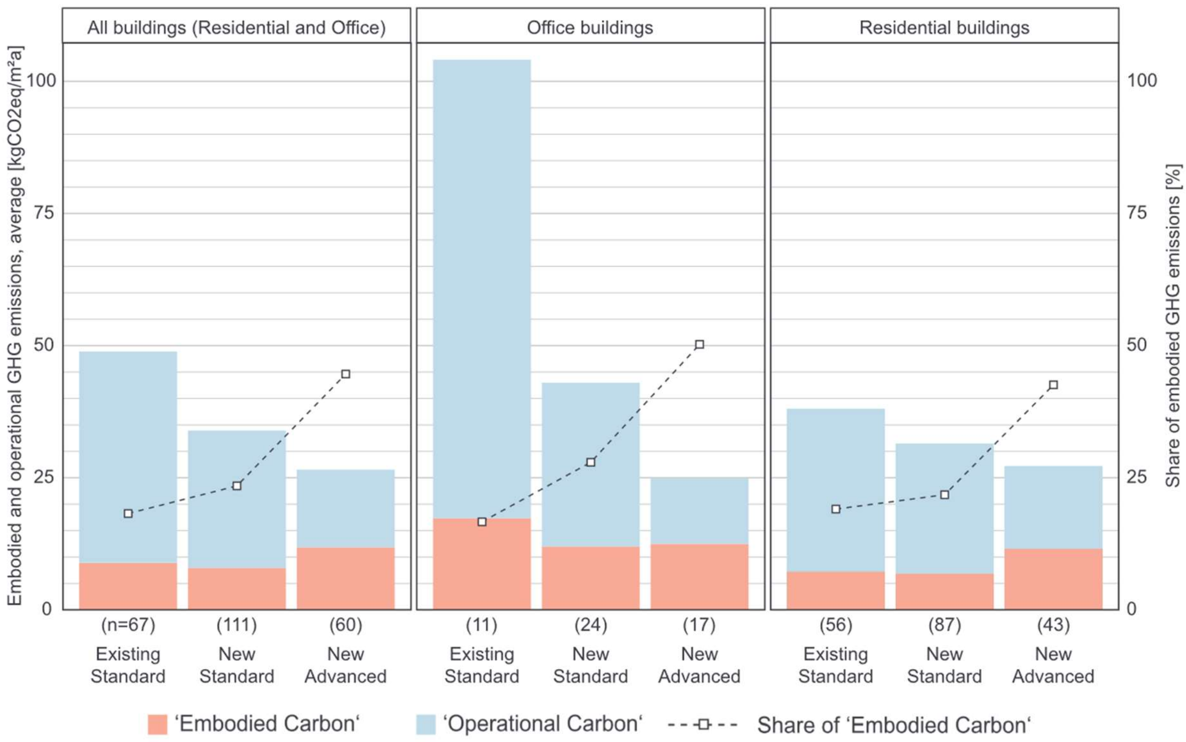
Figure 1.2: Life-cycle stages from BS EN 15978:2011 (Trovato et al., 2020), carbon phases have been highlighted

Globally, a good amount of research on LCA studies on the carbon emissions of buildings has been conducted. The majority of these studies are based on only one or a few case study buildings, often focussing on a specific region or country. According to Kayaçetin & Tanyer (2018), many published studies lack transparency to fully understand the researcher's boundaries and requirements, and assumptions. This causes subjectivity and uncertainty, which makes studies hard to compare. Nevertheless, some studies subjected a detailed review and screening of a larger number of LCA studies, to identify the distribution of embodied versus operational carbon.

Ibn-mohammed et al. (2013) studied the impact of embodied against operational carbon in buildings, to identify the distribution. The authors examined existing literature on LCA studies in different countries. The results show that there is an increasing proportion of embodied carbon. They stated that the rise was mainly a consequence of efforts to reduce operational carbon, such as improvements in regulations for better building performance.

A more recent study by Rock et al. (2020), systematically reviewed over 230 building LCA studies, based on 54 global studies. Including different building types and ranging the buildings' energy performance from 'Existing standard' to 'New advanced' (figure 1.2).

To make a fair comparison, all case studies were brought back to the same reference study period of 50 years. According to the findings, the share of embodied carbon is rising too and above a 1:1 ratio (embodied: operational). While the average share of embodied carbon from buildings that comply with the current energy performance regulations is approximately 20–25% of whole-life carbon, this figure escalates to 45–50% for highly energy-efficient buildings and surpasses 90% in extreme cases.



Figuur 1.3: Global trends in embodied and operational, life cylc GHG emissions (Röck et al, 2020)

Ibn-mohammed et al. (2013) and Röck et al. (2020), indicate an increase in embodied carbon in both relative and absolute terms. Furthermore, they predict that this share will rise even more considering technological advances and stricter energy performance regulations for the operational phase.

However, the precise contribution of embodied carbon and operation carbon may vary considerably depending on the type and function (e.g. office, residential) of the building (Luo et al., 2019). Furthermore, the lifespan of the building is decisive as well, although Röck et al (2020) brought back all the reviewed buildings to the same reference study period of 50 years, in practice, there can be a major difference in lifespan across buildings (Andersen & Negendahl, 2023). Moreover, the environmental life cycle performance of a building also depends on factors such as requirements for user occupancy and behavior (Rasmussen et al., 2018). According to Alotaibi et al., 2022, other factors such as location and climate can also considerably influence the distribution of embodied and operational carbon.

Nevertheless, LCA studies have led to the recognition of the growing fundamental role that embodied carbon plays in buildings. Especially in highly energy-efficient buildings that are complying with the highest energy performance regulations, the share of embodied carbon can be significant.

Rasmussen et al (2018), examined a vast body of LCA studies on buildings but focused on the distribution of embodied carbon across the building life cycle stages. According to the authors, the product stage (A1-A3) is typically responsible for the majority (64%) of embodied carbon (figure 1.3). This is also acknowledged by Röck et al. (2020), which referred to this stage as the "carbon spike from initial carbon investments". Other important stages are the replacement (B4) and the End of life stage (C3+C4). However, the share of these stages is significantly lower than the product stage.

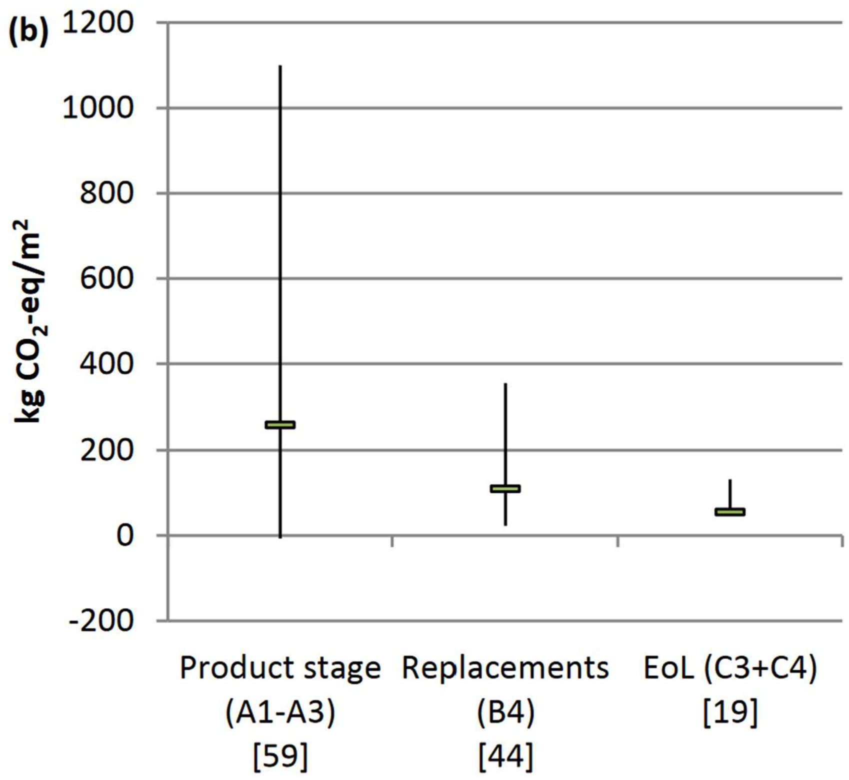


Figure 1.4 Embodied carbon averages and ranges from selected reported life cycle stages. Square brackets indicate the number of case studies included in the displayed ranges (Rasmussen et al., 2018)

1.2.2 Approaches to reduce embodied carbon during the design process

Next to the studies that highlight the importance of embodied carbon as described in the previous section, there are also studies providing strategies for reducing embodied carbon emissions. Pomponi & Moncaster (2016) systematically reviewed over 100 academic articles that provided reduction strategies. They identified that good design practice and appropriate design choices were found to be crucial strategies for embodied carbon mitigation, as well as the selection of alternative low embodied carbon materials.

LCA can be used during the design process to assess the embodied carbon impact of different design choices. However, according to Roberts et al (2020), in current practice, LCA is typically used late in the design process, when it is too late to significantly affect the design (figure 1.6). LCA is still seen to be an additional aspect to the design process, rather than an integral part of the design process. The widescale adoption of LCA within the design process is hindered by various barriers, including; the accessibility of detailed information, time requirements, and the appropriateness of tools for early-stage use (Roberts et al., 2020).

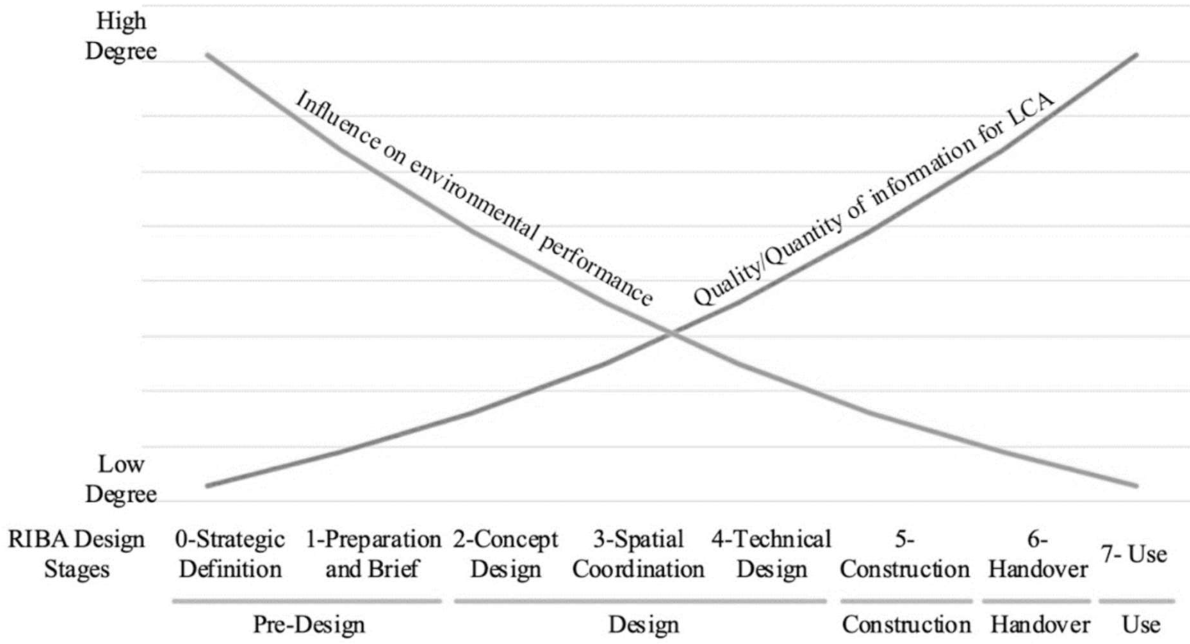


Figure 1.5: The ability to influence environmental performance through the design process (Roberts et al., 2020)

Over the past decade, several studies on embodied carbon reduction approaches during the early design process have been conducted.

Basbagill et al (2013), presented a method for applying LCA to early design stage decision-making, to inform designers of the environmental impact and importance of building component materials and dimensioning choices. Through a case study, they identified building components with their related embodied carbon impact, to realize which design decisions achieve the greatest embodied carbon reduction. The results show that the proposed method can assist in the building design process by highlighting the early-stage decisions.

Häkkinen et al (2015), introduced a wider scope to reducing embodied carbon during the design process of buildings. Through interviews with architects and a case study, the authors outlined a framework, in which they identified important objectives, deliverables, and milestones necessary for reducing embodied carbon throughout the entire design process from a designer's perspective. In addition, the roles and responsibilities of relevant project team members (Client, Architect, Structural Engineer) were identified and added to the framework. Although providing guidelines for all individual design phases, they stressed the importance of early design stages concerning embodied carbon.

Sturgis (2017, chapter 2), proposed a similar type of guideline as Häkkinen et al (2015), which is also based on the Royal Institute of British Architects (RIBA) plan of work design stages. Although, this research took the perspective of a different actor within the project team, namely the 'carbon consultant'. Sturgis (2017, chapter 2), argues that, in theory, it should be possible to be as precise about embodied carbon, as about cost estimates at the design stage assessments. The carbon consultant should be able to know the embodied emissions cost throughout the design process. Currently, it might be difficult to accurately assess the embodied carbon costs in the early phase. However, by practical completion, it must certainly be possible to know the embodied carbon costs with a high degree of accuracy, according to Sturgis.

Marsh et al (2018), developed a simplified embodied carbon tool, to explore how embodied carbon data can be made more accessible for non-technical project team members, during the early design process. Their theory was that if embodied carbon impacts are to be more successfully integrated into the early design process, simpler (LCA-based) tools that can offer more accuracy while requiring few generic parameters are required. The authors concluded, that is it possible to develop simplified embodied carbon tools for the early design process, which deliver greater precision while using fewer parameters.

1.3 Research problem

Recent studies show the growing relative and absolute contribution of embodied carbon in buildings, due to innovations and technological advances in the area of energy efficiency (Ibn-Mohammed et al., 2013; Röck et al., 2020). Although the precise contribution of embodied carbon and operation carbon may vary considerably depending on factors such as the type and function of the building (Luo et al., 2019), the building lifespan and location, and climate (Alotaibi et al., 2022), in general, the share of embodied carbon in buildings is approximately 45–50% for highly energy-efficient buildings and is expected to rise even more in the future (Röck et al., 2020).

This growing contribution has also been noticed by other researchers over the past decade, which have proposed strategies to reduce embodied carbon, and good design practice and appropriate design choices were found to be crucial strategies for embodied carbon mitigation (Pomponi & Moncaster, 2016). Throughout the literature, the importance of the early design process when it comes to influence on the embodied carbon reduction potential has repeatedly been emphasized (Häkkinen et al, 2015). Although there are methods such as LCA to asses embodied carbon during the early design process. In current practice, LCA is typically used late in the design process, when it is too late to significantly affect the design (Roberts et al, 2020). The main barriers are the availability and accessibility of detailed data and the appropriateness of tools, methods, and guidelines for early-design process use. Several studies have proposed such tools, methods, and guidelines to include embodied carbon during the early design process. These studies are either aimed at designers (Basbagill et al, 2013), based on the perspective of designers (Häkkinen et al, 2015), directed at carbon consultants (Sturgis 2017, chapter2), or intended for non-technical project team members (Marsh et al, 2018).

However, these studies omit to aim at and include the perspective of a crucial actor in the early design process; the real estate developer. Therefore, it is unclear for real estate developers how to include embodied carbon in the early design process of buildings. While real estate developers have an important decision-making role during the design process when they act as the client (Häkkinen et al., 2015), and can be seen as the 'spider in the web' in building development (Blok, 2018). Furthermore, real estate developers are in general responsible for the 'cradle to handover' modules, which include the product stage (A1-A3), where the majority of embodied carbon is typically situated (Rasmussen et al., 2020). With this research, the gap is filled by developing guidance for real estate developers on how to steer on including embodied carbon during the early design process.

1.3.1 Problem statement

It is unclear for real estate developers how to steer on including embodied carbon during the early design process, to achieve net-zero carbon building ambitions. There is insufficient knowledge available in science and practice about the opportunities and challenges in meeting net-zero carbon building ambitions, as well as the embodied carbon criteria and assumptions that influence and inform real estate developers during the early design process. Furthermore, it is unknown what activities and actors are required during the process.

1.4 Research relevance

As explained in the previous section, it is unclear for real estate developers how to steer on including embodied carbon during the early design process. Simultaneously, this also provides an opportunity to improve the traditional early design process for the better. To achieve the ambitious net-zero carbon objectives, business-as-usual practices should change. A rethinking of the early design process could challenge and change the established regime in the building and construction industry and accelerate efforts to meet the ambitions of a net-zero carbon built environment.

1.4.1 Societal relevance

The societal relevance of this research mainly concerns the urgent need to decarbonize the construction and building sector, to avoid a catastrophic climate breakdown. Reaching net zero emissions at a sectoral and global level by 2050 asks for a different approach to building development. This research aids to contribute to reducing the carbon footprint of the construction and building sector, by proposing guidelines for real estate developers. Considerable improvements can be made to the traditional design process by including carbon mitigation approaches from the start. Operational carbon mitigation approaches have already made significant progress in the overall carbon emissions of a project. However, given the growing importance of embodied carbon, it is time for real estate developers to factor these emissions in as well. Currently, this is not standard practice in the Netherlands, and even when embodied carbon is assessed it is done when the design or building is already delivered, through what is called a 'Milieu Prestatie Gebouw' (MPG). Therefore this research is especially relevant to the Dutch context.

1.4.2 Scientific relevance

The scientific relevance of this research mainly relates to adding a new perspective to the embodied carbon debate and gaining insight into how real estate developers can contribute to reducing the embodied carbon footprint of buildings. To this point, the perspective of the real estate developer has largely been left out in embodied carbon reduction approaches in the built environment. Moreover, this research adds to the existing knowledge of what might be considered early in the design process. Furthermore, this research contributes to the role and responsibilities of design team members during the early design process. In addition, knowledge is added on the upcoming phenomenon of net-zero carbon buildings, enriching the limited literature available on this topic.

1.5 Research question

The main research question that is answered in this research is:

How can real estate developers steer on including embodied carbon during the early design process to achieve net-zero carbon building ambitions?

Sub-questions:

1. ***What are the opportunities and challenges for real estate developers in achieving net-zero carbon building ambitions by including embodied carbon?***

2. ***What are the criteria and assumptions related to embodied carbon that can inform and influence early design process decisions for real estate developers?***

3. ***What are the actors and activities required during the early design process to achieve net-zero carbon building ambitions?***

4. ***How can early design process guidelines be described to steer on including embodied carbon and achieve net-zero carbon building ambitions?***

1.6 Research purpose

1.6.1 Goal and objectives

The primary goal of this research is to provide knowledge and know-how for real estate developers in the form of guidelines required for steering on including embodied carbon during the early design process and thereby achieving net-zero carbon building ambitions. The objectives are to explore the opportunities and challenges in achieving net-zero carbon building ambitions and understand the criteria and assumptions related to embodied carbon. Identifying the actors and activities that are required during the early design process to achieve net-zero carbon building ambitions, to develop guidelines on how to steer on including embodied carbon.

1.6.2 Deliverables

This thesis aims to deliver early design process guidelines on how to steer on including embodied carbon. Furthermore, for and through this research a prototype that translates these guidelines into to visual representation is created.

1.6.3 Dissemination and audiences

This research is aimed at real estate developers that want to gain more insight into how to take embodied carbon into account when developing (net-zero carbon) buildings. This can either be developers who have already committed to developing net-zero carbon buildings (frontrunners) or developers who will might be obliged to develop net-zero carbon buildings in the future, by stricter regulation and want to learn how to prepare for it (followers).

For the frontrunners, the result of this research could help to improve their early design process. This will not only bring them closer to their net-zero carbon ambition but also reduces the amount of carbon emission that needs to be offset, which has significant sustainable and financial benefits.

For the followers, the result of this research could help to become more aware of the impact of embodied carbon and increase their understanding of embodied carbon in the design process. The result will further spread the knowledge already obtained by the frontrunners among the followers, to strive towards a net-zero carbon built environment.

1.7 Research structure

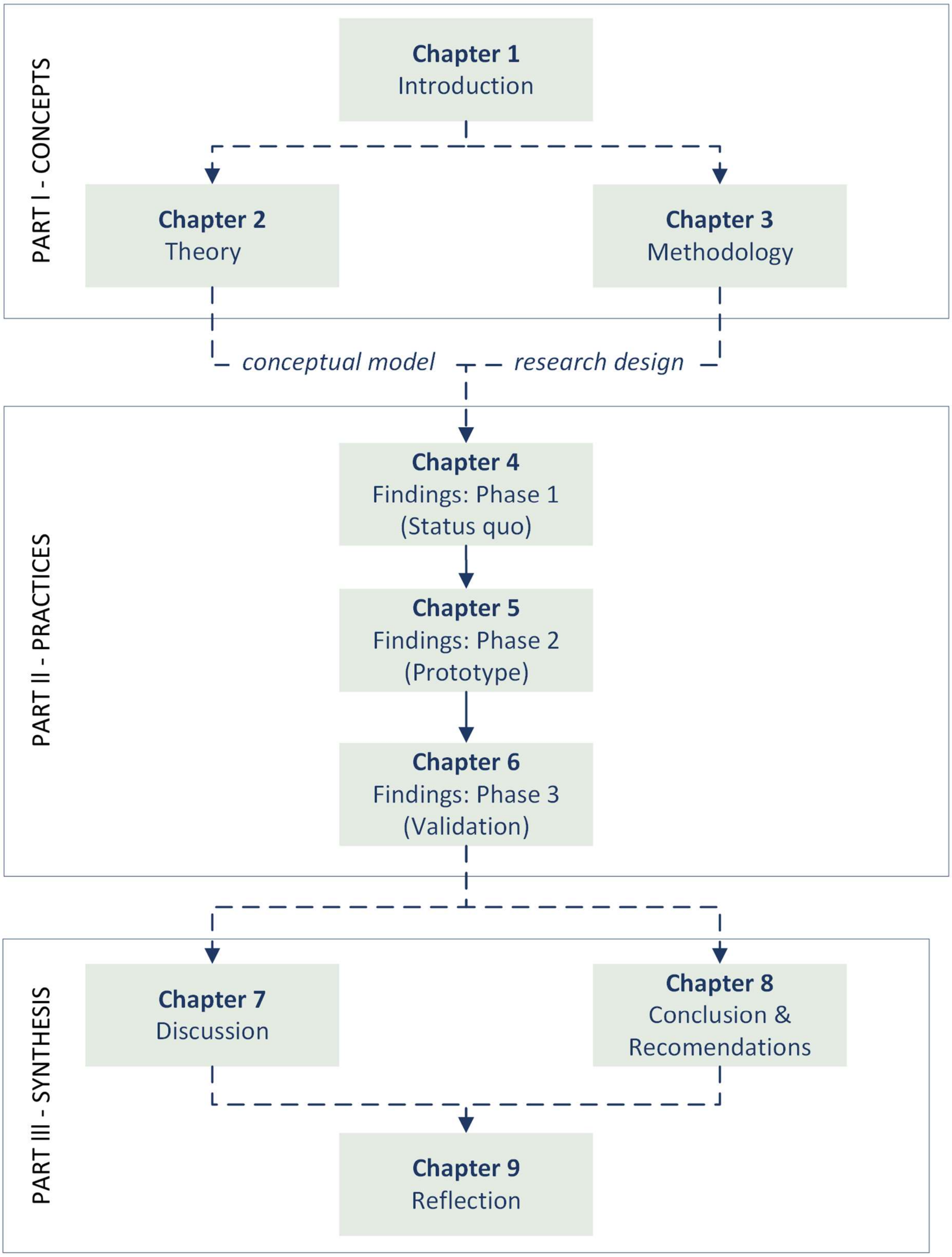


Figure 1.6: Research structure (Own ill.)

Chapter 2

Theoretical background

/02 Theoretical background

2.1 Net-zero carbon buildings

2.1.1 Definition

The concept of "Net-zero carbon buildings" has received little attention in the literature, this might be because several definitions and similar terminologies are circulating in the scientific domain.

'Net-zero carbon building' can be traced back to the concepts of *nearly zero-energy building* (NZEB), *zero-energy building* (ZEB), and *net-zero energy building (NZEB).* Most of these concepts are addressing the operational energy use of the building. The underlining standard definition of these concepts can be defined as; "a high-performance building with very low energy demand, which makes use of on-site or off-site renewable energy sources to cover their demand" (Grover, 2020). More recently, the concepts of *zero carbon building (ZCB) and net-zero carbon building* (NZCB) were introduced. For these concepts, an underlining standard definition is harder to give. While some relate it to buildings with zero carbon emissions in the operational phase, others include embodied carbon emissions as well (Grover, 2020).

According to Attia (2018, Chapter 2), "Ambiguity and vague terminology and definitions in the green building practice reduce the likelihood of building professionals' adherence. It leads to inconsistent interpretations and, as a result, to inappropriate performance variation and construction errors.". Therefore, a consensus and adoption of a standard definition is required. Especially, knowing that when a concept grows in significance, so do the terminology and definitions associated with it. Which in turn, increases the risk of misunderstanding (Attia, 2018)

For this research, the following definition of a ***'net-zero carbon building'*** **(NZCB)** is used, adapted from the Science Based Targets initiative (2021); "A building where, in addition to net zero operational carbon, embodied carbon across the building lifecycle is reduced to a level that is consistent with reaching net zero at the global or sector level in 1.5C pathways. Any residual emissions that remain unfeasible to eliminate should be neutralized through offsetting."

2.1.2 Embodied carbon targets

Setting the right targets from which will be offset is crucial in developing net-zero carbon buildings, as otherwise every building could be labeled as 'net-zero carbon' by just offsetting all remaining carbon emissions. To achieve net-zero carbon at a global level, the underlying source of the problem must be tackled instead of fighting the symptoms.

Approach 1: Setting a target based on the current practice

To start setting a target, a baseline on the average business-as-usual embodied carbon numbers could be helpful. Currently, there is no unified consensus on what this average might be, according to the most recent report of the world building council for sustainable development (wbcsd & Arup, 2023). In the same report, an educated guess is made on the average upfront (A1-A5) value, setting the business-as-usual benchmark on 800 kgCO_2e/m2. Important to note is that while the substantiation of this average value is valid, it is based on LCA studies from buildings that have been calculated with the consent of the building owner. Building owners and developers that do not put carbon high on their agenda, might not perform an LCA study, therefore the actual value might be higher. Nevertheless, taking this benchmark and knowing that carbon emissions must be halved by 2030, setting the target of 400 kgCO_2e/m^2 would represent a favorable value according to the world building council for sustainable development (wbcsd & Arup, 2023).

Approach 2: Setting a target based on the 1.5-degree carbon budget.

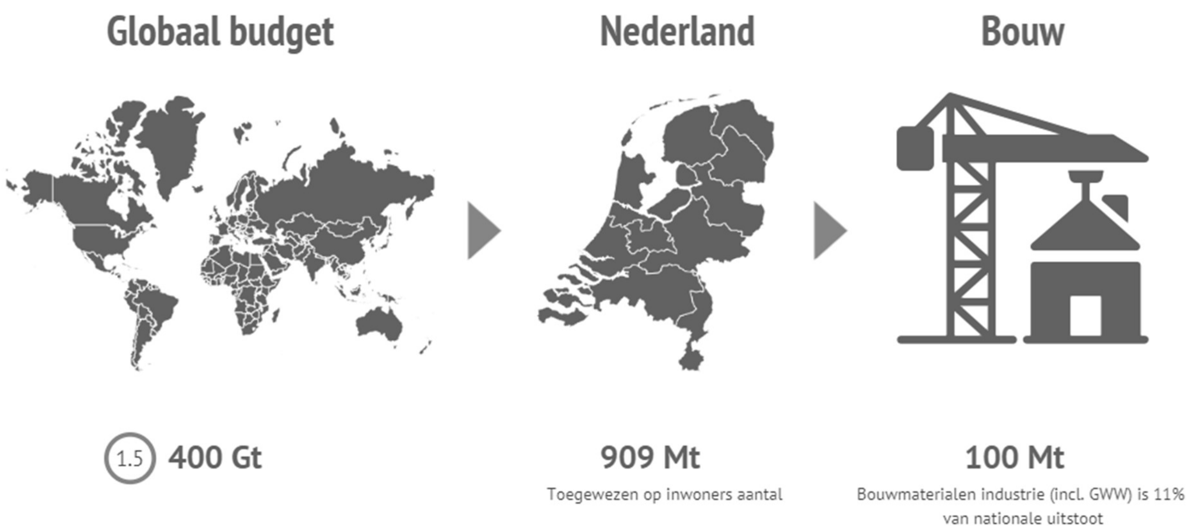


Figure 2.1: Carbon budget for the Dutch construction sector ()

The Dutch Green Building Council (DGBC) takes another approach to target setting. Instead of starting from the current practice, they look at the total carbon emissions that we are still allowed to emit in order to remain within the 1.5 degrees of global warming as stated in the Paris Agreement. This results in a total remaining carbon budget for the Dutch construction sector of 100 Mt (figure 2.1). As a result, the DGBC formulated target values per m^2 for different building types (table 2.1). Currently, the target values are around 200 kgCO_2e/m2. However, these targets are indicating a reduction towards 2050, which is tightened every three years. When achieving the target the building can be labeled 'Paris proof' by the DGBC.

Table 2.1: Paris Proof embodied carbon targets new development (DGBC, 2021)

Paris Proof limit values	embodied carbon kg CO_2-eq. per m²			
	2021	2030	2040	2050
Residence (single-family home)	200	126	75	45
Residence (multi-family home)	220	139	83	50
Office	250	158	94	56
Retail real estate	260	164	98	59
Industry[5]	240	151	91	54

Table 2.2: Paris Proof embodied carbon targets renovation (DGBC,2021)

Paris Proof limit values	embodied carbon kg CO_2-eq. per m²			
	2021	2030	2040	2050
Residence (single-family home)	100	63	38	23
Residence (multi-family home)	100	63	38	23
Office	125	79	47	28
Retail real estate	125	79	47	28
Industry	100	63	38	23

The DGBC target is half as low as the ***embodied carbon target*** set by the world building council for sustainable development, indicating that there is, like the business-as-usual average, no unified consensus on the appropriate target. The DBGC sets a lower target for renovation projects (Table 2.2). Setting a different target for renovation projects seems appropriate. However, it does raise questions on what count as renovation and what counts as new development.

2.2.2 Carbon offsetting

The complex nature of building construction in today's society makes that even after a vast reduction in carbon emissions, some emissions are unavoidable (Sturgis, 2017). For that reason, buildings can only be labeled as "net-zero carbon" by offsetting the remaining carbon emission, to reach an overall impact of zero carbon into the atmosphere. ***Carbon offsetting*** can be used to compensate for or neutralize a carbon emission that occurs elsewhere. According to Allen et al. (2020), There are two ways to generate carbon emission offsetting; emission reduction and carbon removals.

Emission reduction includes avoided emissions, for example by replacing a planned fossil fuel power plant with a renewable energy source. Paying someone to avoid harm to natural and semi-natural ecosystems is theoretically a method of emission reduction. Carbon removals are offsets produced by programs that remove carbon from the atmosphere directly. Examples are; the planting of trees, soil carbon enhancement, and the convention of atmospheric carbon into rocks through remineralization.

The majority of offsets available today are emission reductions. Although required, emission reduction is insufficient to reach net-zero emissions in the long run. Carbon removals, on the other hand, provide an important benefit over emission reductions since they remove emissions from the atmosphere, according to Allen et al. (2020). The procurance of these high-quality carbon offsets should be done through a third party to avoid claims of "greenwashing" (World Economic Forum & JLL, 2021). Non-governmental organisations (NGO's), non-profit entities independent of governmental influence, are emerging to make sure that the carbon offsets are verified and publicly disclosed.

2.2.4 Carbon Pricing

Carbon pricing is a method of converting carbon emissions into financial costs that is used by both corporations and governments to help reduce emissions and meet climate goals (Carbon Pricing Leaderschip Coalition, 2018). In Dutch practice, many different prices, circulate for the emissions of a ton of carbon. According to "het klimaat verbond" (2021), it is quite arguable that different price levels are used for different purposes. A lower price can be used to curb activities with a high climate impact, while in other situations even a high price will hardly influence a decision. Although it does require transparency about the purpose and the reason for the chosen price.

Figure 2.2: Carbon prices in the EU (Center for European Reform, 2022)

Putting an internal price on carbon can help in decision-making, as this exposes the shadow costs of different options. Using a carbon price for estimating the offsetting cost, on the other hand, requires a more precise approach. Certainly, because offsetting prices are linked to the global and continental trade prices, through the ***emission trading system (ETS).*** This is a financial instrument from European union to reduce carbon emissions. Emissions rights can be bought, however, the number of available emission rights is limited and decreases every year (Gerlagh et al., 2022). Carbon prices in the European Union have risen from around 20 euros per ton of CO2 in 2019 to 90 euros and above in 2022 (Figure 2.2). Although ETS is aimed at large corporations and countries, and this carbon price is not directly linked to the voluntary carbon offset market, the increasing rate does indicate that carbon will increasingly become a more prominent factor in pricing, Indicating that the price of carbon-intensive materials will likely increase. Prices on the voluntary carbon offset market,

2.2 Embodied carbon

2.2.1 Definition

Embodied carbon (kgCO2e) is used to describe the carbon emissions that occur during the extraction of raw materials, manufacturing, transportation, construction, maintenance, replacement, deconstruction, and disposal. When communicating the embodied carbon impact of buildings, referring to which of the building life cycle stages are included is crucial. Although there are many possible ways to refer to which stages are included, in reports and literature there are two main collective names used.

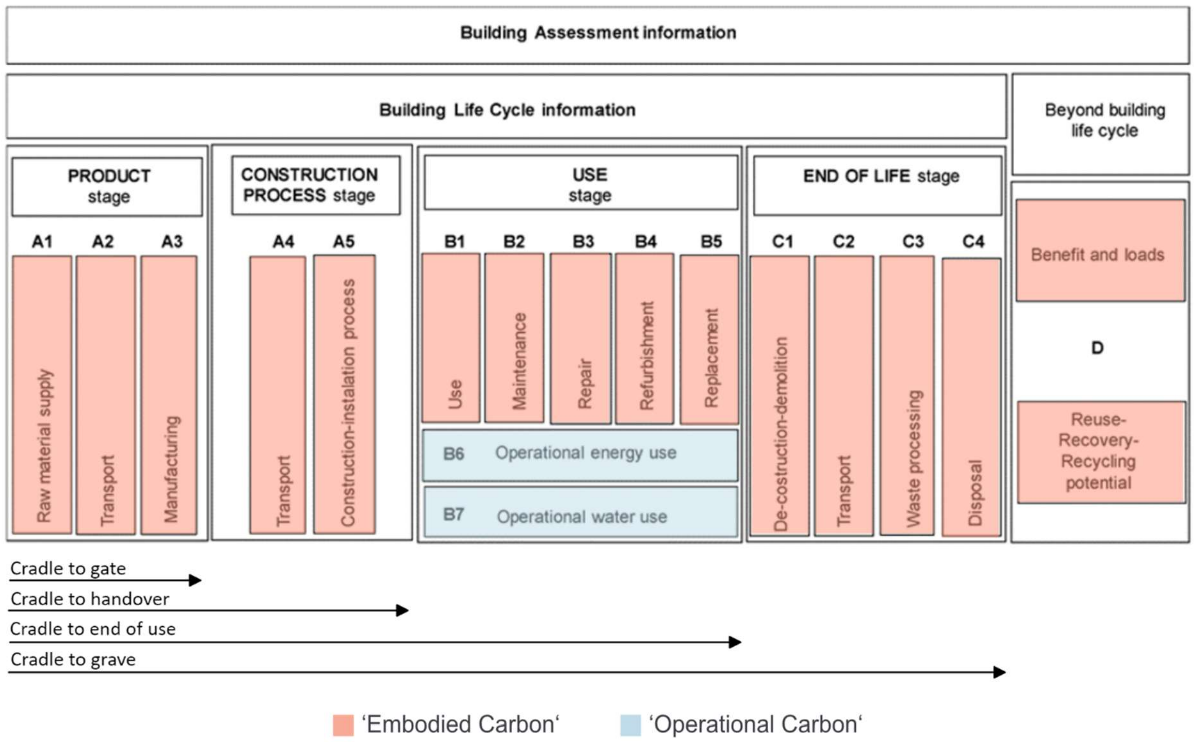


Figure 2.3 : Life-cycle stages from BS EN 15978:2011 (Trovato et al., 2020), carbon phases have been highlighted.

The first one is ***life cycle embodied carbon***, which refers to the carbon emissions associated with Modules A1–A5, B1–B5, and C1-C4 (Institution of Structural Engineers, 2020). The second one is ***upfront embodied carbon***, also known as embodied carbon to practical completion, and refers to the carbon emissions associated with Modules A1-A5 (Institution of Structural Engineers, 2020). Practical completion is an important moment in building development as this is the moment after which the building is taken into use and the operational carbon start. At this moment in the building life cycle, it is relatively simple to calculate the embodied carbon impact of the previous stages. As buildings have a long lifespan and it is unsure what will happen to the building when it is in use, it is hard to predict the embodied carbon over the lifecycle of buildings. Furthermore, the vast majority of embodied carbon is typically situated up until practical completion (Rasmussen et al., 2018; Röck et al., 2020). For this reason, embodied carbon targets are often set for upfront embodied carbon.

2.2.2 Carbon assessment

As explained in the introduction, ***Life cycle assessment (LCA)*** is the most developed and used method to assess embodied carbon in the building sector (Amiri et al., 2021). LCA studies have led to the recognition of the growing fundamental role that embodied carbon plays in buildings (Ibn-Mohammed et al., 2013; Pomponi et al., 2018). Although LCA is considered a reliable, effective, and useful analysis method (Kayaçetin & Tanyer, 2018), there are still several issues with conducting LCA studies. They are data-intensive and time-consuming procedures (De Wolf et al., 2017; Häkkinen et al., 2015), especially when considering all stages and including all building elements in a building with a high level of detail. Furthermore, data on the material production and environmental impact of building products are often missing (Pomponi et al., 2018), which makes it hard to make comprehensive and accurate estimates.

In the Netherlands LCA's studies on buildings are communicated within the '**Milieuprestatie Gebouw' (MPG)**. The MPG indicates the environmental impact of the materials used in a building. It is developed by the Dutch national government to unequivocally and verifiably calculate the material-related environmental performance of buildings over their life cycle. The MPG is expressed into one value that represented the shadow costs (Zizzo et al., 2017). All new residential and office buildings over 100 m^2 applying for a building permit are required to provide an MPG. The MPG has a maximum limit value of 1.0 for Offices and 0.8 for residential buildings, and the goal is to gradually tighten the required value and eventually halve it by 2030 (RVO, 2017)

The environmental performance of a product is used as an input in the LCA analyses. **Environmental product declaration (EPD),** which complies with applicable International Standard Organization (ISO) requirements, is used to communicate a product's environmental performance on a global scale (Del Borghi, 2013). EPDs are independently verified and registered to share data transparently and comparably (Institution of Structural Engineers, 2020) According to Harnot & George (2021), EPD is thought to be the most reliable source of data regarding a product's impact on the environment. Due to the methodological developments in recent years, manufacturers of construction products increasingly publish data on their products using EPD (Röck et al., 2020). Despite being a fast-growing trend brought on by consumer desire for "transparency" from manufacturers regarding sustainability claims (Zizzo et al., 2017), currently, only a limited amount of products have an EPD. When a product does not have an EPD, or the producer does not provide data in another way, more generic data can be used as input for the LCA study. However, for reliable results, there must be a certain amount of validation and clear reporting of the data's quality. Additionally, EPDs can be used to gain life cycle assessment credits in certification schemes, including LEED, and BREEAM, (World Economic Forum & JLL, 2021)

According to Kayaçetin & Tanyer (2018) utilizing a national database is a common strategy to enhance data quality. In the Netherlands, data is stored in a national EPD database: ***Nationale Milieu Database (NMD)***. Currently, it is obliged to use this database when calculating the MPG for a building permit request. Within the database, three categories of data are distinguished. Category 1: contains brand-specific data from manufacturers and suppliers, which is tested by a qualified independent third party. Category 2: contains brand-independent data from groups of manufacturers and industries, which is also tested by an independent third party and publicly available with mention of representativeness. Category 3: contains brand-independent data, which are more generic and not tested.

2.2.3 Carbon assessment instruments

As explained in the previous section, embodied carbon in buildings is assessed by conducting LCAs. However, the method is just one element when it comes to assessing carbon, the second element is the tool that is used to assess the carbon footprint.

Currently, there are many calculation instruments used to assess a building and calculate its carbon footprint, both for research and practical purposes. Generic (web-based) tools such as; EC3 or Simapro. These tools are often free to use and provide an estimate of the carbon footprint. They are developed to be highly simplified, allowing architects, engineers, and builders to easily comprehend the possible impact of various building materials and designs. One of the key features of these tools is that they often have a limited database or a database with environmental product declarations (EPDs) for different building materials. The accuracy of the estimate depends on the quality and completeness of the database used by the tool. Certain components of LCA are either ignored or set to default in online tools to simplify the evaluation approach for non-LCA practitioners. (Grover, 2020). Spreadsheet-based instruments, such as "One-click LCA" or "GPR materialen", make use of Life cycle inventory to assess the carbon footprint of a building. Later in the process, more detailed BIM-based instruments can be used (e.g. BIMpact). These software programs require data (quantities and environmental impact of materials or components) from either their database or a national database. According to De Wolf et al. (2017), many of the current instruments are not transparent or up to date.

2.2.3 Embodied carbon over the building layers

When addressing embodied carbon in buildings, it is critical to understand which building element is accountable for how much embodied carbon. Knowing where to focus is especially important while undertaking reduction approaches. Brand (1994), describes a building as a part of elements. These elements, also known as the S-layers, together compose a building. His principles are based on the lifespan of various elements and products in construction. The carbon impact of the building layers highly depends on the expected lifespan.

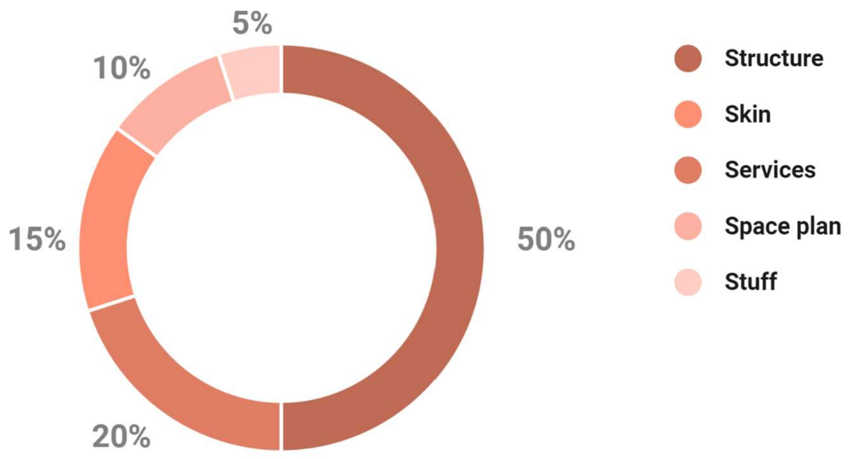
Structure (30-60 years): The structural skeleton of a building determines its basic shape. Typically responsible for 50% of the total embodied carbon footprint.

Skin (30-35 years): The outside layers of a building such as a façade, including windows, surface material, and insulation. Typically responsible for 15% of the total embodied carbon footprint.

Services (20-30 years): Services such as smart energy systems, lighting, and air conditioning support the internal climate of a building. Typically responsible for 20% of the total embodied carbon footprint.

Space plan (10-30 years): The materials used for compartmentalisation: suspended ceilings, raised floors, and all internal surface finishes. Typically responsible for 10% of the total embodied carbon footprint.

Stuff (5-10 years): Everything else that comes in a building with the final tenants. The furniture, the electronics, the decoration, etc. Typically responsible for 5% of the total embodied carbon footprint.



Figuur 2.4: Estimated typical upfront embodied carbon (A1-A5) distribution (wbcsd & Arup, 2023)

2.2.3 (Biogenic) carbon sequestration

In the embodied carbon debate, it is inevitable not to mention carbon sequestration*. **Carbon sequestration*** is a phenomenon of absorbing carbon from the atmosphere, through natural processes such as photosynthesis in plants and trees (Grover, 2020). When using these plants and trees in building materials, these (bio-based) materials become carbon sinks, capturing carbon and preventing it from being released into the atmosphere for a period of time. Which can result in a low or negative embodied carbon footprint of building components and therefore in a building that "captures" carbon. As a rule of thumb, a ton of C02 is sequestered by 5 trees of 40 years of age (Carbonify, 2015). The MPG now ignores this storage period and mixes all positive and negative CO2 emissions into an overall score. The inclusion of biogenic carbon is however debated since it is unclear what will happen with materials after there are no longer in use.

2.3 The early design process

2.3.1 Definition

As explained in the introduction, the importance of the early design process when it comes to the influence on environmental performance is repeatedly emphasized throughout literature and practice. However, what exactly is the early design process? The first step in answering those questions is looking at the design process as a whole. According to the Royal Institute of British Architects (RIBA) Plan of work and the Dutch plan of work (DNR-STB 2014) (Table 2.1), there are several stages within the design process of buildings. Each stage corresponds to the tasks that need to be performed during that phase of the process. The RIBA stages are used within this research as they are well-defined and used throughout (inter)national literature.

Table 2.3: Stages of design in accordance with RIBA Plan of work and Dutch Plan of work (DNR-STB)

	RIBA Plan of Work	**Standaardtaakbeschrijving (DNR-STB 2014 -The Dutch plan of work)**
Early design	0 Strategic definition	1 Initiatief Haalbaarheid
Early design	1 Preparation and Brief	2 Project definitie
Early design	2 Concept design	3 Structuurontwerp
Early design	3 Spatial coordination	4 Voorontwerp
		5 Definitiefontwerp
	4 Technical design	6 Technisch ontwerp-Bestek
		7 Prijs-en constractvorming
	5 Construction	8 Uitvoeringsgereed ontwerp
		9 Directievoering
	6 Handover and close out	-
	7 In use	10 Gebruik-Explotatie

Both RIBA Plan of Work and the Dutch Plan of work (DNR-STB) do not specify what stages are considered early. As there is not a clear dividing line between the early and late design process, in this research, when referring to ***the early design process*** the following stages are included: Strategic definitions (Initiatief Haalbaarheid), Preparation and Brief (Project definitie), Concept design (Structuurontwerp) and the first part of the spatial coordination (Voorontwerp).

2.3.2 Low embodied carbon design assumptions

When considering low embodied carbon design decisions, it is important to get a feeling for the underlying design assumptions that can reduce the embodied carbon footprint of a building, especially from the early design phase (Pomponi and Moncaster 2016).

First of all, Smaller aspect ratios and greater areas per storey lead to a higher floor space-to-envelope area ratio. This has been shown to reduce not only heating and cooling loads, but also embodied carbon and cost per floor space (Gauch et al., 2023) The size and design of a structure have a significant impact on both embodied and operational efficiency, especially in residential buildings. The ramifications of selecting a building size and shape should be thoroughly addressed when planning and developing a new development. Building compactness was found to significantly reduce embodied and operational impacts.

Furthermore, the column grid size has a high influence on the embodied carbon footprint. The span of the floor plate between columns and walls can significantly impact the total quantity of material required to properly accomplish the same overall functional need, which is directly related to the over carbon footprint. (wbcsd & Arup, 2023). Floors typically account for the majority of the embodied carbon in the structure, while columns only account for a small percentage . As a general rule, it can be assumed that a smaller grid-size leads to thinners floors and, as a result, a reduced embodied carbon footprint. While a high amount of columns might be undesirable, it is nevertheless important to calculate the carbon footprint of different options, even a small change in grid size can have a considerable impact.

In the embodied carbon debate, often the consideration to choose either concrete, steel or timber emerges. It is commonly known that most of the time timber performs best in tests (even without considering carbon sequestration potential), as timber avoids the need for carbon-intensive manufacturing processes (Morris et al., 2021). However, there are a lot of different variants and combinations possible between these different structural materials. Searching for new uncommon (hybrid) combinations can significantly reduce the embodied carbon footprint. For example, TT concrete slabs supported by timber columns and beams are an unconventional solution, but have a relatively low environmental impact and work well with offices with a flexible floor layout (van den Dobbelsteen et al., 2007). In a hybrid structure, manufacturers can deploy different materials more to their optimum performance. By requestion unconventional innovative structural combinations, the current construction industry will be challenged to create low embodied carbon solutions.

Although Timber is becoming increasingly recognized as a sustainable building material that can replace concrete and steel, there is also a general understanding that we still need concrete and steel in our constructions. That being said, when considering reinforced concrete the most impactful way to reduce the embodied carbon footprint is to use less of the most polluting elements: cement and reinforcing steel (wbcsd & Arup, 2023). Making the concrete industry more sustainable, starts on the demand side. This can start by requesting a certain carbon footprint and the use of secondary materials per m3 of concrete. The concrete industry has to look for lower embodied carbon footprint alternatives, through for example the use of geopolymer concrete reinforced with non-corrosive basalt fiber-reinforced polymer to replace cement and reinforcing steel in structures (Huang et al., 2023)

When looking at the skin, a large percentage of glass surfaces are popular in modern building designs, especially for inner-city developments. Having a lot of glass has numerous benefits (more daylight, a more generous sense of space, appearance, connection to outdoor space, etc.). However, glass has a high embodied carbon footprint. By limiting the glass surface, emissions from the façade are kept to a minimum (Sobota et al., 2022). There are a lot of factors, like the location of the building, the orientation of the openings, and the indoor climate concept, that are decisive in choosing the amount of glass. Therefore, an energy model should be combined with the analysis of embodied carbon

Next to glass, building insulation plays an important role in the skin of the building. The European market of building insulation materials is dominated by mineral (e.g. glass and stone wool) and fossil (e.g. EPD, PUR, XPS) fuel-derived insulation materials that offer the best performance in terms of unit cost (Habert et al., 2020). These conventional insulation materials are effective to lower the operational carbon in buildings but have a high embodied carbon footprint. Using bio-based insulation alternatives (e.g. Woodfibre, Cork, Cotton) offers several advantages. First of all, the embodied carbon footprint is typically significantly lower and these natural insulation materials have a high percentage of renewability, that can easily overcome the 50% (Grazieschi et al., 2021). Another important advantage of natural insulation materials is their carbon sink potential. Their footprint can count as negative when considering the carbon caught during the growth of the virgin materials (Grazieschi et al., 2021).

2.4 The real estate developer

2.4.1 Definition

According to Adams and Tiesdall (2012) the real estate developer's role is to oversee the development process. They are in charge of managing the process and the parties involved (e.g., designers, engineers, and contractors) (figure 2.5). There are many distinct types of developers, ranging from independent developers, who are generally small-sized and operate in a niche market, to developers associated with building companies and investment developers, who are often focused on long-term returns and are related to institutional investors (Nozeman and Fokkema, 2008). Developers are described as a 'mediator', because they are occupied with identifying solutions and getting to a consensus with the main parties involved (van den Brink, 2022). To reach a consensus, real estate developers are informed on all kinds of disciplines and at the same time have influence on these disciplines.

This research is specifically aimed at ***real estate developers*** of (mix-used) inner city building developments of medium to large scale, which can be categorized as the investment developers type. Due to the complex nature of inner-city developments, it could be argued that the barrier to developing net-zero carbon buildings is higher than in the less complex outer-city greenfield developments. Moreover, inner-city developments are often highrise, tall building design is considered resource intensive due to the intensified use of materials and the infrastructure requirements around these projects. (Pomponi et al., 2018).

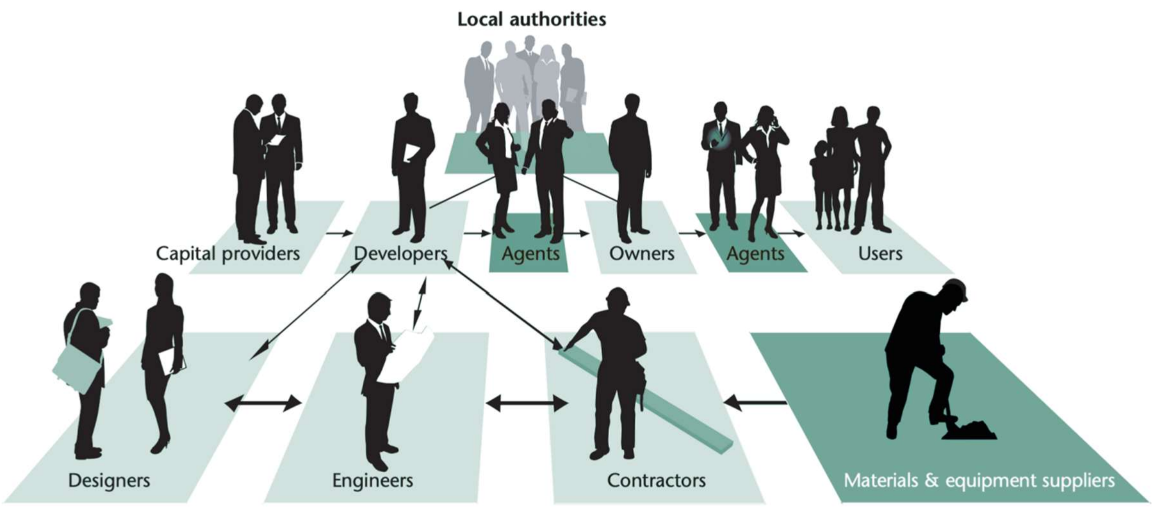


Figure 2.5: The complex value chain in (area) development (van den Brink, 2022)

2.5 Conceptual framework

To provide a clear overview of the research, it is necessary to connect the main concepts that are introduced before. The conceptual framework (figure 2.6) illustrates the presumed relationships between these main concepts. The framework further helps to address the research questions and their dependence on one another. The real estate developer is at the center of the framework, connected to the three main concepts of this research: Embodied carbon, Net zero carbon building, and Early design process. As shown, this conceptual framework does not have a start and end as the concepts are all connected. However, the concept of net-zero carbon building can be seen as the starting point, as this is the ambition that needs to be achieved. Embodied carbon is in the way of achieving this ambition. Within the early design process, there are solutions to tackle issues surrounding embodied carbon, thereby getting closer to the ambition of net-zero carbon buildings.

Main research question: How can **real estate developers** steer on including **embodied carbon** during the **early design process** to achieve **net-zero carbon building** ambitions?

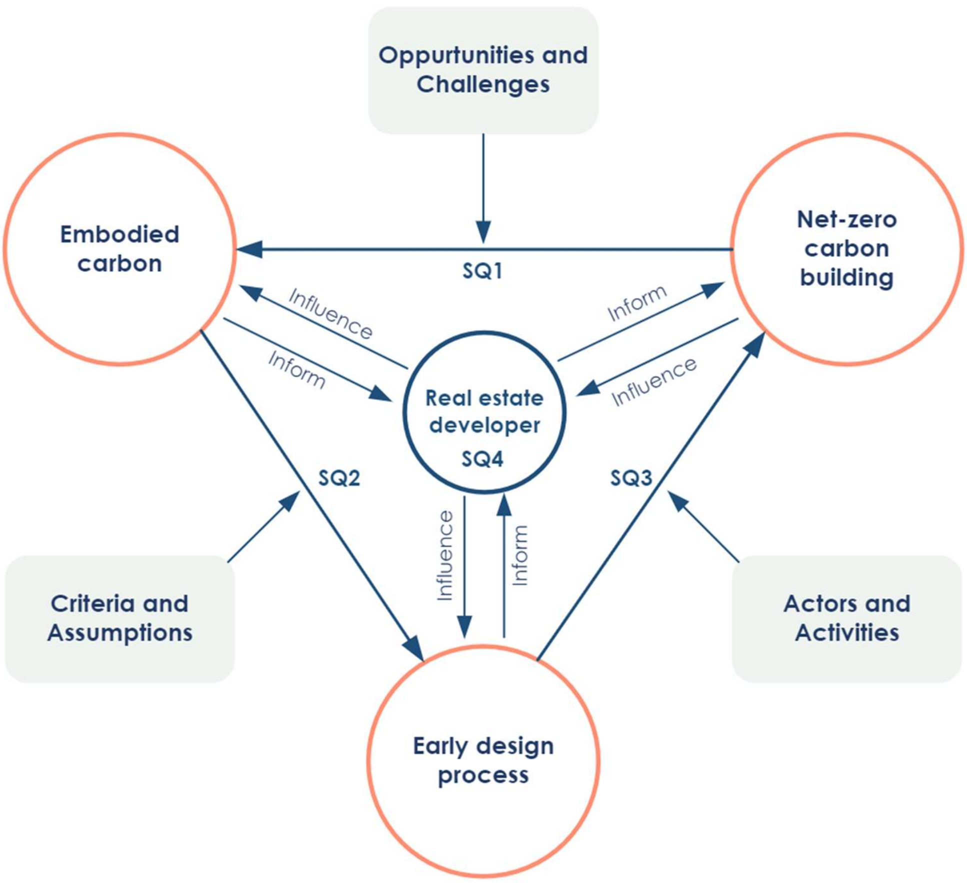


Figure 2.6: Conceptual framework (own ill.)

Chapter 3

Methodology

/03 Methodology

In this chapter, the research methodology used in this research is presented and underpinned. First, an explanation of the type of study is given. Thereafter, the research design and the ways of collecting and analysing data are discussed. The chapter ends with the data plan and ethical considerations.

3.1 Type of study

According to the research onion model by Saunders et al. (2019), conducting research consist of several layers, and "There are important outer layers of the onion that you need to understand and explain rather than just peel and throw away" (Saunders et al., 2019). Before delving into the data collection and analysis, which is at the core, first the choices made to come there need to be explained.

This research aims to generate a new process and guidelines for real estate developers, by exploring the interaction and collaboration required to include embodied carbon in the early design process. Therefore, the appropriate philosophy for research is **interpretivism** as " The purpose of interpretive research is to create new, richer understandings and interpretations of social worlds and contexts. For business and management researchers, this means looking at organizations from the perspectives of different groups of people." (Saunders et al., 2019). The social world and context are in this research the early design process and the main perspective is that of the real estate developer.

The approach to theory development, or logic of inquiry (Blaikie & Priest, 2018), related to interpretivism is typically **inductive**, according to Saunders et al. (2019). As the research topic is new, exciting much debate and there is little existing literature, an inductive approach, which starts by collecting data to generate or build a theory (often a conceptual framework) may be applicable.

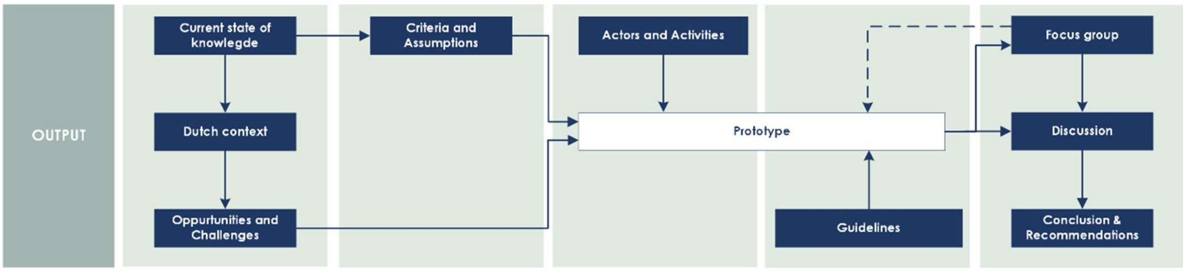
According to Blaikie & Priest (2018), "Qualitative methods are concerned with producing discursive descriptions and exploring social actor's meanings and interpretations.". Deriving from the aim of this research, the related philosophy, and the theoretical approach, the use of **qualitative methods** seems to be the appropriate choice for this research.

3.2 Research design

In this section, the research design is described. As explained in the previous section, qualitative methods are used in this research to answer the research questions. Each method relates to a sub-question and at least one of the objectives. An overview of the research design is provided in table 3.1

Table 3.1: Overview of the research design (own ill.)

	DESK RESEARCH		EMPIRICAL RESEARCH		VALIDATION
METHODS	LITERATURE REVIEW		RESEARCH THROUGH DESIGN		FOCUS GROUP
SUB-QUESTION	1	2	3	4	-
OBJECTIVE	**Explore and expose** the opportunities and challenges, for real estate developers in the Netherlands, related to	**Understand** the criteria and assumptions related to embodied carbon and the phases that are part the early design process	**Identify** the relevant actors within the early design process and the activities that need to be completed to steer on embodied carbon.	**Develop** guidelines for real estate developers that assist in steering on including embodied carbon and achieve net-zero carbon building ambitions	**Validate** the findings and improve the prototype



3.2.1 Literature review

A literature review of the main concepts was conducted to broaden the theoretical background and develop the conceptual framework. Although the literature related to embodied carbon in the early design process is limited, and even more so on net-zero carbon buildings, it was still crucial to take the literature as a starting point. In addition to academic literature, reports and documents (inter)national building organisations were consulted to develop the theoretical background. Both sub-question one and two were answered through the literature review.

Sub-question 1: ***What are the opportunities and challenges for real estate developers in achieving net-zero carbon building ambitions by including embodied carbon?***

Objective: **Explore and expose the opportunities and challenges for real estate developers related to net-zero carbon buildings and embodied carbon.**

Sub-question 2: ***What are the criteria and assumptions related to embodied carbon that can inform and influence early design process decisions for real estate developers?***

Objective: **Understand the criteria and assumptions related to embodied carbon and the phases that are part of the early design process.**

3.2.2 Research Through Design

Research through design (Rtd), was the selected method for the empirical research part. This method was used to generate new knowledge that is not easily obtained through traditional research methods. One of the most important aspects of research through design is that it seeks to provide explanations or theories within a broader context (Frankel & Racine, 2010). In Rtd, an artifact is designed that exists on the ideas, skills, and knowledge of the researcher and which can be experienced by others, often referred to as a prototype (Giaccardi, 2019). The prototype act as the carrier of information and a tool to facilitate communication. Furthermore, according to Michel (2007), the designing act of creating prototypes is in itself a potential generator of knowledge.

The main reason for choosing Rtd is that the ultimate goal of this research was "The primary goal of this research is to provide knowledge and know-how for real estate developers in the form of guidelines required for steering on including embodied carbon during the early design process and thereby achieving net-zero carbon building ambitions. ". By using Rtd this knowledge and know-how is provided through a visual and useable tool, instead of in text like in other often used methods. Both sub-question three and four are answered through empirical research. How the primary data to answer these questions was collected and analysed is explained in section 3.3.

Sub-question 3:	***What are the actors and activities required during the early design process to achieve net-zero carbon building ambitions?***
Objective:	**Identify the relevant actors within the early design process and the activities that need to be completed to steer on embodied carbon.**
Sub-question 4:	***How can early design process guidelines be described to steer on including embodied carbon and achieving net-zero carbon building ambitions?***
Objective:	**Develop guidelines for real estate developers that assist in steering on including embodied carbon and achieve net-zero carbon building ambitions**

3.2.4 Validation

Two separate focus groups were consulted to validate the findings and improve the prototype. Within a focus group, the emphasis lies on a particular topic, and several people are placed together to discuss this topic (Bryman, 2012). The first focus group was an internal session with five real estate developers and one sustainability expert. In this focus group session, the prototype was first discussed both on style and content. Thereafter, statements were shown on which the participant could either disagree or agree and give their explanation. The second focus group was an external session with the design team members that were interviewed before. This validation session particularly focused on comparing the findings from the interviews to the prototype.

3.3 Data collection and analyses

During the research, the researcher was conducting a graduation internship at Edge. The core business of Edge is real estate development, mainly in the Netherlands, but also in other countries such as Germany, United Kingdom, and the United States. This real estate developer is responsible for the development of the project used in this research. Last year, Edge committed to being “net-zero”, which means that their company, on average, puts no carbon emissions into the atmosphere. This not only entails company-related emissions but also the carbon emissions coming from their projects. The first project that needs to comply with this commitment; the Jaarbeurs plein project, was used by the researcher to collect data. This project acted as the “status quo” of developing an inner-city mixed-used net-zero carbon building. The data was collected through semi-structured interviews with the design team members of the project: Real estate developers, Architects, MEP consultants, Building physics consultants, Structural engineers, Cost consultants, and Sustainability consultants. In addition to the semi-structured interviews, explorative interviews were conducted with real estate developers to set requirements for the prototype and inquire about net-zero carbon and their knowledge and understanding of embodied carbon. The interviews were conducted both face-to-face and in online meetings and a content analysis of the transcripts was used to analyze the data

3.4 Data plan

The data management plan (DMP), was created using the TU Delft DPMonline platform. DMP plan explains how the data for this research project was collected, documented, and stored throughout the research. Furthermore, it explains how it will be shared afterward. When creating The DMP, it showed that was a high chance that confidential data would be used during the research. To manage this, information that is under embargo was only stored in the company's storage one drive.

3.5 Ethical considerations

As part of the DMP, Legal and ethical requirements questions needed to be answered. The answer to all the ethical-related questions was ‘no’, As a result, it was assumed that no substantial ethical difficulties were involved in this research project. However, as mentioned above, this research dealt with confidential data. Therefore, this data was only described on an aggregated level and no personal information is added (names of the interviews and participants of the focus group were not mentioned).

Chapter 4

Findings: Phase 1 (Status Quo)

/04 Findings: Phase 1 (Status Quo)

The first phase of the findings is concerned with understanding the current situation (Status Quo) on how embodied carbon is currently included throughout the early design process of a state-of-the-art building project. Tensions and contradictions are identified through interviews with design team members and analysed using activity theory. Which are used as input for the prototype that is presented in the second phase of the findings (Chapter 5).

4.1 Project and interview description

4.1.1 Description of the project

The project that plays a central role in this research and is used to represent the current best practice of including embodied carbon is called the 'Jaarbeursplein' project. This state-of-the-art mixed-used high-rise building is planned to be built in the heart of the city of Utrecht (Figure 4.1). The design has a gross internal area of approximately 45.000 square meters, dived over a variety of functions; recreational, commercial, and office. The ambitions for this building are high striving for a net-zero carbon status. The project was tendered by the Municipality of Utrecht, to design a striking and vibrant sustainable building. The construction is set to start in 2025, with the expected delivery in 2028.

Figure 4.1: Jaarbeursplein project (Edge,2023)

4.2.1 Description of the design team Interviews

Semi-structured interviews were conducted with design team members of the Jaarbeursplein project, as explained in the methodology section. The primary goal of the interviews was to gather input for the prototype. This was done by reflecting on the early design process of the Jaarbeursplein project, which was at the end of the sketch-design (concept design) when the interviews took place. In addition to reflecting on the process, there was room to brainstorm together with the interviewees on how improvements could be made. As the design team consisted of a large number of organisations and people, a selection was to interview at least one person from each organisation. The interviews took place both face-to-face and online. The following design team members were interviewed:

- *Real estate developer*
- *Architect*
- *Structural engineer (2)*
- *Supplier (façade/solar panels)*
- *Building physics consultant (2)*
- *Sustainability consultant*
- *Cost consultant (2)*

4.2 Activity Theory

According to Engeström (2001), activity theory is a way to understand how human beings interact with their environment and how they engage in purposeful activity to achieve their goals. Engeström argues that when individuals and groups encounter contradictions or tensions within their activity systems, expansive learning occurs. In this research, the activity theory framework is used to understand the current situation and identity the tensions and contradictions within the activity of "including embodied carbon". The contradictions or tensions can arise from a variety of sources, such as conflicts between the community and the subject, miscommunication in the division of labour, or mismatches between individual and project objectives. On the next page, the interactive elements within the activity theory framework (Figure 4.2) are explained. Through a content analysis of the interview transcripts and the use of the activity theory framework, tensions and contradictions during the early design process of the Jaarbeursplein project were identified.

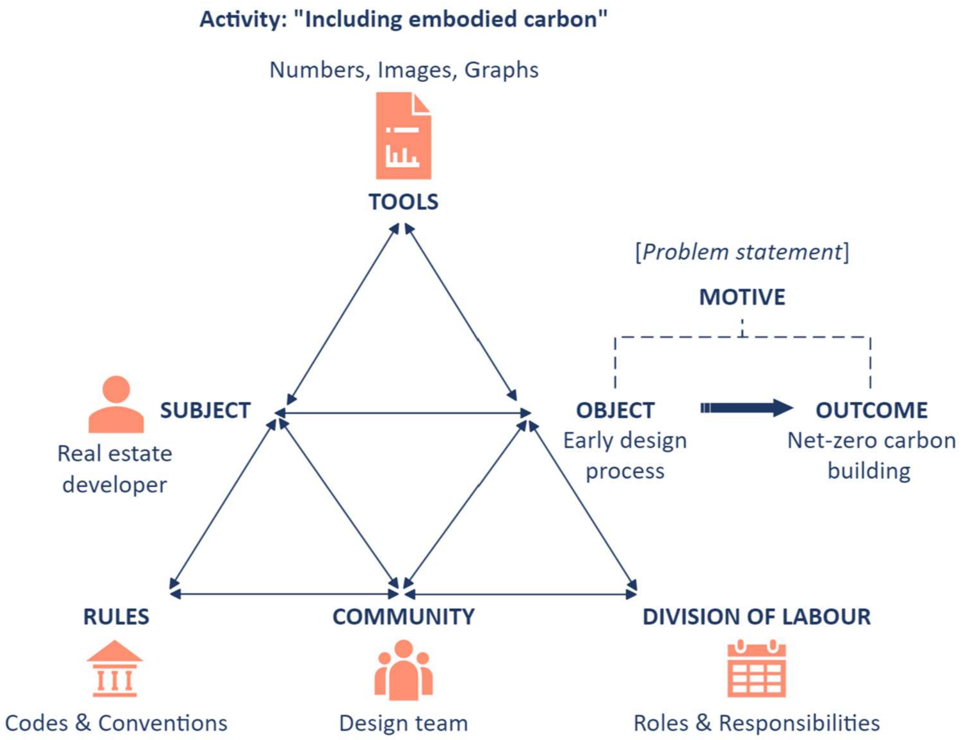


Figure 4.2: Activity theory frame work of including embodied carbon (own ill. Based on (Bitzer et al., 2018)

SUBJECT: Real estate developer

The subject refers to the person or people that are engaged in the activity who are the focus of a study on the activity (Bitzer et al., 2018). In other words: the point of view used to focus on the activity. Since this research is aimed at real estate developers, they are the subject.

TOOLS: Carbon assessment methods

Tools are the physical objects & systems of symbols such as language, and mathematics that people use to accomplish the activity (Bitzer et al., 2018). In this case, the tools are the images, graphics, and numbers that are used to communicate the embodied carbon amount and options.

OBJECT: Early design process

The object refers to the problem space in which the activity takes place. In this research, the problem space is defined as the early design process.

MOTIVE: [Problem statement]

The motive is the purpose/reasons for the activity. The purpose/reasons for including embodied carbon are described in the introduction chapter and summarized in the problem statement.

OUTCOME: Net-zero carbon building

The outcome is the desired goal of the activity. Including embodied carbon in the early design process, has as a goal to achieve net-zero carbon building targets.

DIVISION OF LABOUR: Roles & Responsibilities

The division of labour explains how the work in the activity is dived among the participants in the activity (Bitzer et al., 2018). For this research, it is especially interesting to understand how the roles and responsibilities are divided among the design team members.

COMMUNITY: Design team

The community can be described as the people, and groups whose knowledge, interest, stakes, and goals shape the activity (Bitzer et al., 2018). In this case, the design team (often existing of an Architect, Structural Engineer, Cost consultant, and MEP consultant)

RULES: Codes & Conventions

The rules are the laws, codes, conventions, customs, and agreements that people adhere to while engaging in the activity (Bitzer et al., 2018). For this research, there is a focus on particularly the codes and conventions within the construction industry, which may or may not be adhered to by the real estate developer and the design team, while creating the building design.

4.3 Tensions and contradictions

4.3.1 The target

Tension: The real estate developer is uncertain about the target

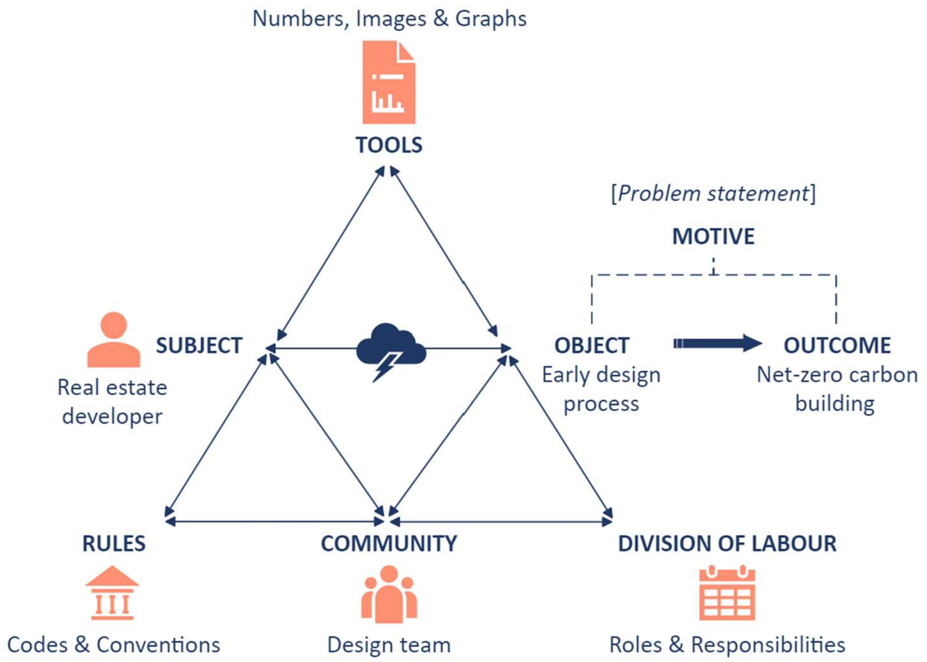


Figure 4.3: Identified tensions and contradictions visualized in activity theory framework (own ill.)

As explained in the theoretical background chapter, there is no unified consensus on what the embodied carbon target should be. For that reason, the real estate developer set an internal target of 500 kgCO2e/m2 for the upfront embodied carbon and 700 kgCO2e/m2 for the life cycle carbon. This target was not directly communicated with all the design team members, only the structural engineer, building physics, and sustainability consultant said to have heard of the target. The whole design team did, however, know that there was the ambition that the building should be 'net-zero carbon' and that therefore reducing the embodied carbon footprint was important.

According to the Developer and Building physics consultant, the internal targets were achieved quite easily. Therefore, at the end of the concept design stage, it was chosen to try to meet the 240kgCOe/m2 target for upfront embodied carbon, as laid out by the DGBC to be "Paris proof".

'240 kilograms of CO2 per square meter gross floor area. We have now achieved that, or at least, that is calculated based on the MPG. We have calculated towards that number by saying: the concrete must be 80 or 90 percent recycled to achieve this." Developer

The structural engineer also used their internal target for the structure of 150 kgCO2e/m2, based on case studies from the UK. This target was also not directly communicated with either the developer or the design team. The calculated carbon footprint of the structure was 144 kgCO2e/m2, staying under the target. Setting a target for other building layers, such as skin or service, and putting the responsibility per target in the hands of one party, could be beneficial for achieving the target for the whole building. Moreover, it could incentivize innovation and focus effort on high-impact building layers, especially when the target becomes stricter. According to the building physics and sustainability consultant, there should also be different (stricter) targets for re-development and development projects.

"I think it is logical that you have a sharper requirement for re-developments. If you don't, and retain the building structure in a redevelopment project, then you have a huge carbon budget left that you can spend. Then you might think; I'm not going to pay attention to for example the carbon impact of the façade because you don't have a stimulus. On the other hand, If you were to set the strict requirement of re-development for new construction, then it would be completely unfeasible" Building physics consultant

Input for the prototype
• A target per building layer could help to steer the total carbon footprint. This target can be set, based on case studies or the rule of thumb. • There should be different targets for development and re-development projects. • Only when the target is strict enough it will help to steer.

4.3.2 The carbon assessor

Tension: the responsibility of carbon assessment is split between different roles

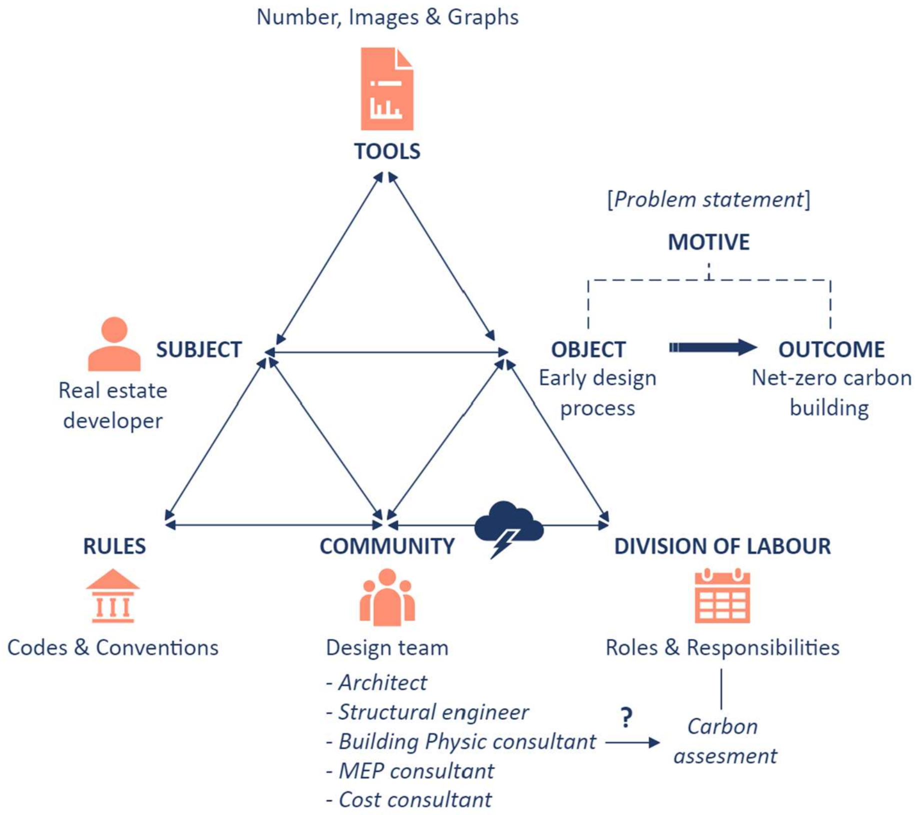


Figure 4.4: Identified tensions and contradictions visualized in activity theory framework (own ill.)

In the Jaarbeursplein project, the responsibility of the carbon assessment was in the hands of two roles: *the building physics consultant* and *the sustainability consultant.* The latter can be considered as an additional role, that normally would not be present within the design team at this stage. The sustainability consultant was, among other things, responsible for conducting the MPG calculations. While the building physics consultant was responsible, next to the typical activities, for the carbon calculation, which was based on the MPG. This division of labour came organically according to the developer, however, in retrospect, it could have better been taken care of by one party the developer admitted. This was also suggested by the Architect and Sustainability consultant, the question remains who should the assessor be?

"If you want to make a whole-life carbon calculation, then you need input from the net-zero energy building (BENG) calculation which is provided by the building physics consultant. The NZEB calculation is often ready sooner. So with an MPG calculation, you are running behind, even behind on the cost estimate, so that is always done at the last moment." Sustainability consultant

As we know from the interviews with developers, three roles might take on the role of the assessor: *the building physics consultant, the sustainability consultant,* and *the cost consultant.* As cost consultants already use quantities of materials to make a cost estimate, adding the carbon impact of these materials per quantity does seem like a relatively easy activity. An additional benefit of leaving the carbon assessment in the hands of the cost consultant can be that the connection between the carbon and costs impact can be made directly. Simultaneously, this might also be a disadvantage as the cost consultant might rank the costs of higher importance than carbon. A sustainability consultant does not have this problem, as their main role is to advise on the most sustainable options. In the end, it is up to the real estate developer to decide to either go for costs or carbon. Therefore having two different voices within the design team might be beneficial.

"Well, what we often do in early stages is, for example, compare different construction principles, study variants and put concrete and steel and wood next to each other. We used to do that only on costs and construction time, but now we also include the carbon, because the demand is there"

Cost consultant

Input for the prototype
• **The responsibility of carbon assessment should be handled by one team member.** • **The cost consultant is in a good position to act as the carbon assessor, as they are already collecting the quantities and materials.** • **The carbon assessor should proactively request information from other team members.**

4.3.3 The carbon reduction

Contradiction: Steering on upfront or lifecycle embodied carbon

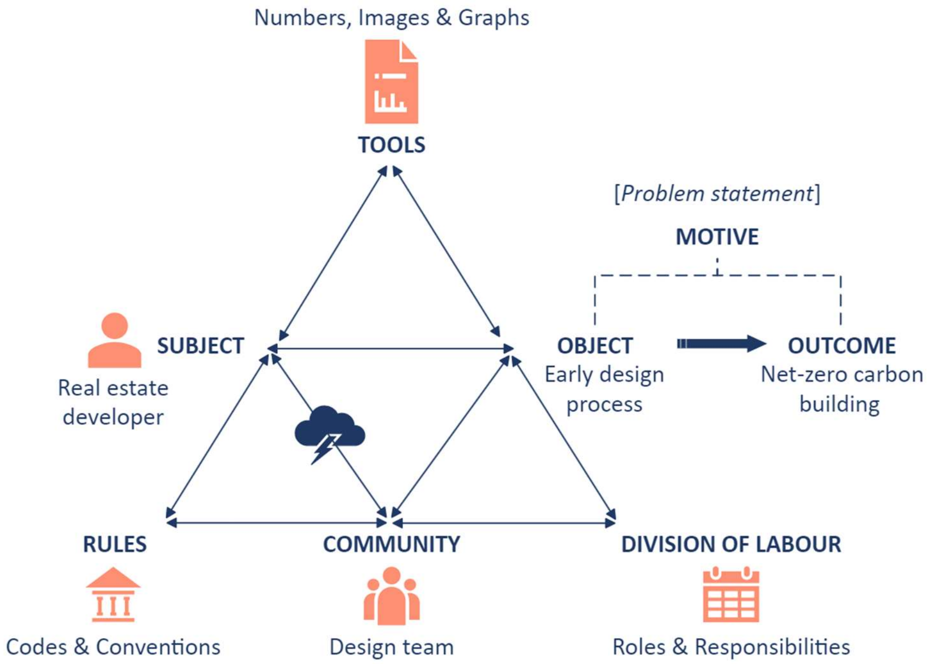


Figure 4.5: Identified tensions and contradictions visualized in activity theory framework (own ill.)

Two perspectives emerge in the carbon debate, and this was also evident in the interviews. Some argue that reducing the upfront embodied carbon should be the primary focus, as this has an immediate impact on the environment. While others argue that the lifespan should be prioritized, as this has a greater long-term impact and reduces the need for frequent replacement and demolitions. According to most of the interviewees, decisions should not only be based on the upfront embodied carbon impact but there is a need for a holistic approach that considers the life cycle as well.

"We focus first on urban qualities and only then on carbon qualities, because also in the first conversations we had with the structural engineer, who said: for us, it is easy if you just make a box, that is most efficient, but that is of course not what was requested." Architect

Reducing upfront embodied carbon still needs to be the main focus in the view of the interviewees, as the developer is responsible until practical completion. The reduction of the upfront embodied carbon mainly involved material substitution in the Jaarbeurs plein project. To also account for the life cycle, design for deconstruction principles, such as making the building components detachable were proposed by the sustainability consultant. Another approach to include life cycle thinking is to communicate both the embodied carbon footprint together with the prospected lifespan in the consideration of building components and materials. This is not only useful in communication but also at practical completion, when the building is handed over to the building owner. Documenting the lifespan of the main building materials, though for example a material passport, could assist the building owner in the considerations of retrofitting the building.

"We now have to steer very much and make an impact, because now, at the moment, it is most important that emissions go down, to stay beneath the 1.5 or 2.0 degrees target. We have to take it as a starting point and hope that in 50 years, 75 years, if the building were indeed demolished, that we would have invented some kind of large carbon vacuum cleaner" Cost consultant

Input for the prototype
• **There is a contradiction on whether to steer on upfront embodied carbon or life cycle embodied carbon, not only between the real estate developer and the design team, but also within the design team.** • **Aim for the reduction of upfront embodied carbon, but use both the upfront embodied carbon footprint and prospected lifespan in communication.** • **Document the expected lifespan of the main building components and communicate both the total embodied carbon footprint and the lifespan with the building owner.**

4.3.4 The carbon assessment

Tension: A late carbon assessment

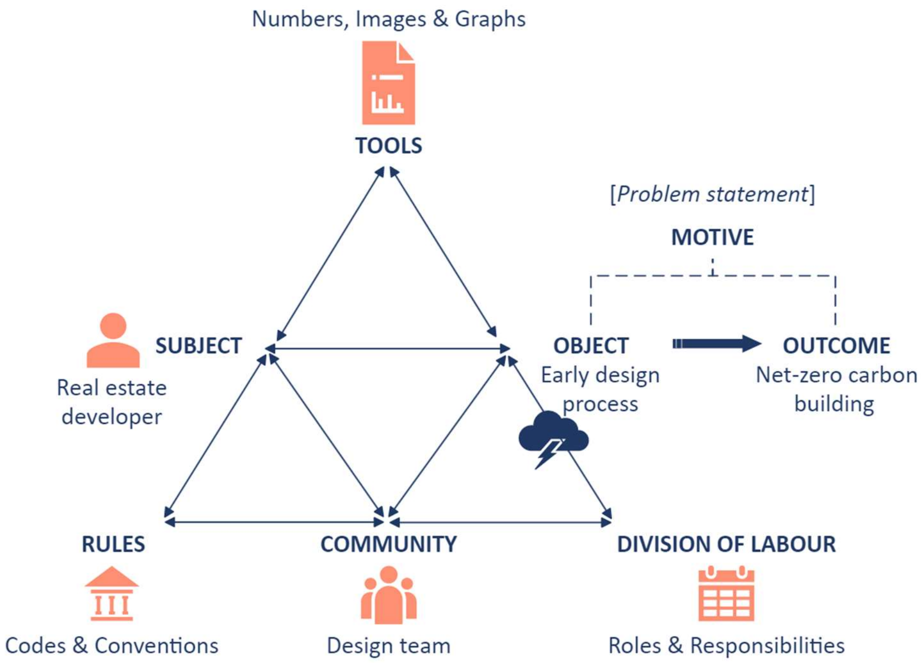


Figure 4.6: Identified tensions and contradictions visualized in activity theory framework (own ill.)

Although the LCA was done at the end of the concept design stage, which is earlier than in most other projects, the real estate developer admitted that it still came late. It has to be noted here that this project was a Tender with a definitive deadline. Nevertheless, this does mean that the assessment did only happen once the architect stopped designing and not gradually during the early design process.

"The MPG calculation came very late, actually much too late, if you ask me because it could have been a nasty surprise and that's also a bit because, and you will see that in every process, your architects like to design for a very long time." Developer

The structural engineer stated that the assessment takes a couple of days to complete and that after the calculations are completed, they are already several decisions ahead, which means that the assessment will not be up to date, but will in the best case provide a good estimate. To still get to a low carbon score, design decisions were made based on both options provided by the structural engineer, the architect, and the sustainability consultant, and on educated guesses, not on estimations.

"You could add some kind of risk surplus to the assessed carbon footprint. That's rarely done internally, because the carbon footprint score has to be sharp" Building physics consultant

Carbon assessment has limitations, one of which, according to the building physics consultant, is that it does not account for a risk surplus in addition to the assessed carbon footprint. This risk can be mitigated by including a contingency, similar to how you would budget money. This would effectively increase the carbon footprint score, potentially making it more accurate but also less favorable.

Input for the prototype
• **The carbon assessment should be done multiple times during the early design process, to steer on estimates instead of on educated guesses.** • **Carbon assessment should be handled as precisely as cost assessment, contingency should be added to the assessed embodied carbon footprint.** • **Communicating the carbon footprint with the design team can create a common goal.**

4.3.5 The Involvement of Suppliers

Contradiction: Certainty about products versus freedom about choice

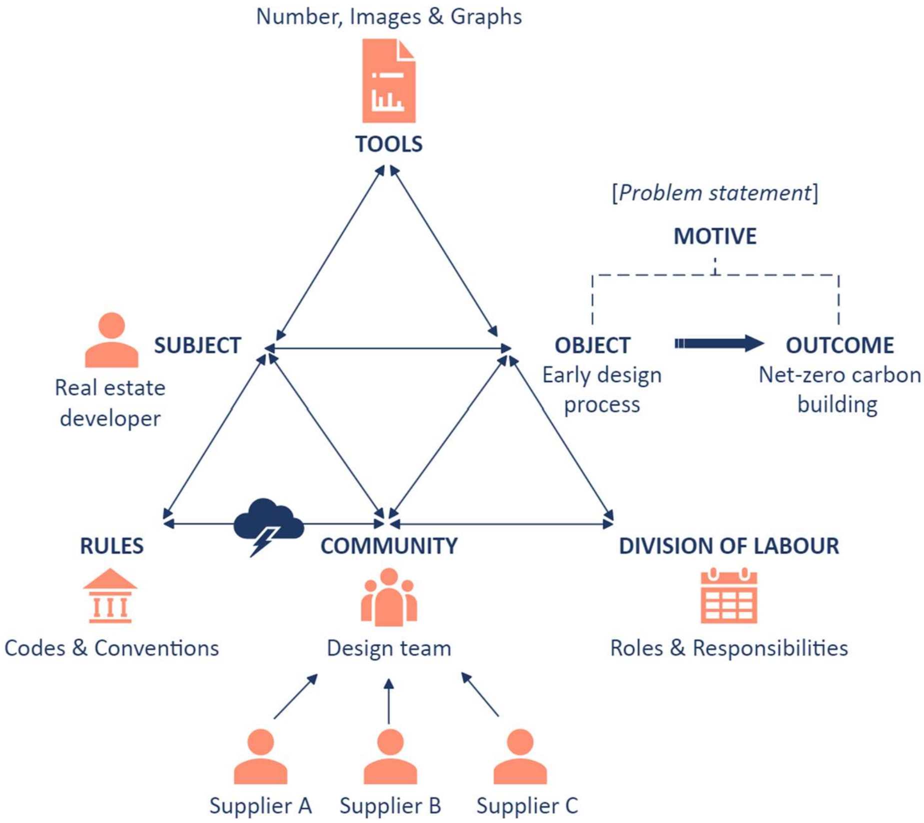


Figure 4.7: Identified tensions and contradictions visualized in activity theory framework (own ill.)

The early involvement of suppliers is becoming increasingly recognized in the construction industry. This approach entails engaging with suppliers of building components and materials, during the design phase. By working closely with suppliers, the real estate developer and design team members can gain a better understanding of the carbon impact, capacities, and limitations of different options to make more informed choices.

"I do see in more and more projects that suppliers are working in from the start. I believe in the trust you create, but of course, it's questionable whether you want to do that on all levels."

Supplier (Solar façade)

In the Jaarbeursplein project, the supplier of façade solar panels was involved from the mid-way of the concept design stage. Initially to bring more information about the energy generation potential of using solar panels on the façade to reach BREEAM requirements. However, collaborating with these suppliers also brought the topic of embodied carbon to the table and the opportunity to bring more detailed data on the carbon impact of materials to the front. Although the supplier did not have EPD on their products, they did exercise LCA's on a couple of their standard products. The reason not to do it for all products is that it would become too expensive.

"If the solar panel has been tested at one meter twenty by ninety and you make the panel one meter forty by ninety and the content does not change that much. You have to make a whole new EPD, according to the EPD authorities, because they make a lot of money that way […] and in any case, we always just want to have a project to which we can at least attribute those costs because otherwise, you would have to invest a lot of money." Supplier (Solar façade)

The real estate developer could help with the issue, and invest together with the supplier in the EPDs, to create category-one data which could lower the embodied carbon amount within the MPG. An additional benefit is that the supplier can also provide a detailed cost estimate. The real estate developer did argue that you need to make sure that you are not completely dependent on a specific supplier, so it would be wise to engage with two of three suppliers. On the other hand, you also want to be able to make decisions fast, and working with one partner is therefore preferred (developer).

"It has quite an effect to be able to choose category-one products instead of category-three products. While you often don't have that information yet. You don't even have a contractor, let alone suppliers." Sustainability consultant

The amount of different suppliers is not the only question, another question is also which type of suppliers should be partnered with. collaborating with suppliers of structural components (e.g. floors) or materials (e.g. timber) would seem appropriate. The same goes for suppliers of building services (e.g. air conditioning). Engaging with all these suppliers may require additional time for research and coordination, which can delay the overall project time. Furthermore, it may limit the ability to change suppliers after the design process is completed and a better choice becomes available.

"You have to be careful that you don't already commit to certain parties if that is not desirable, that you take this one super environmentally conscious product with a low embodied carbon footprint and then not include it in the building specifications in a later stage. That is of course a risk, that you are already pushing the carbon footprint to its limit by choosing specific products." Cost consultant

Input for the prototype
• **Involve suppliers of building components with a high carbon footprint and create EPDs together with suppliers to enter into the NMD.** • **There is a risk that partnering with suppliers could influence the ability to change building components or suppliers later in the design phase. Therefore, the product should be benchmarked with other market parties** • **Partnering with suppliers is a time-consuming activity, the intensity and amount of suppliers should be considered carefully**

4.3.6 The communication

Contradiction: the presumed level of knowledge versus the actual level of knowledge

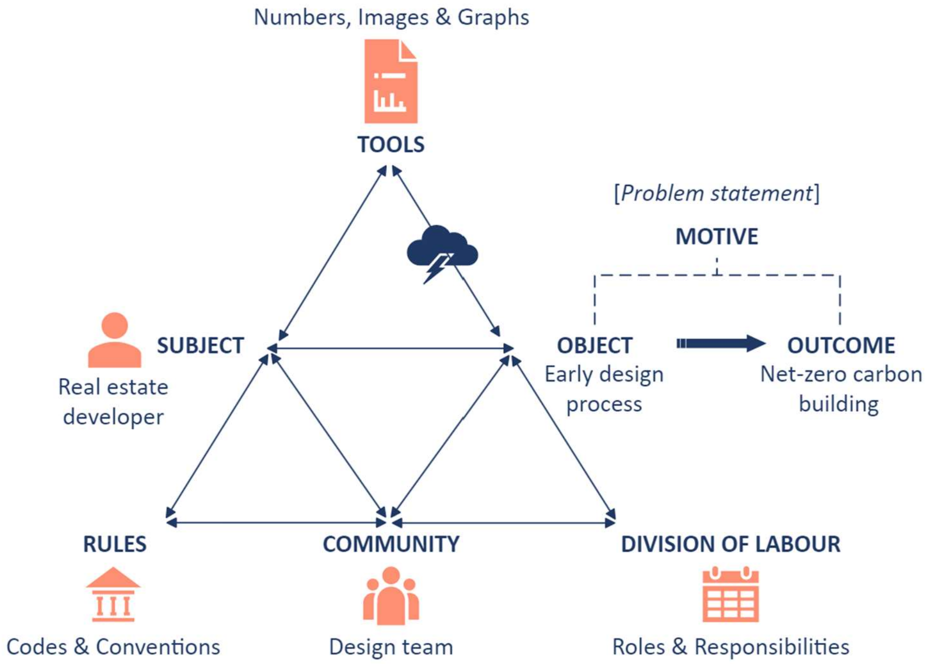


Figure 4.8: Identified tensions and contradictions visualized in activity theory framework (own ill.)

Throughout the interviews with the design team members, but also in the wider carbon debate, the conversation about embodied carbon typically revolves around three materials; timber, concrete, and steel. Concrete and steel are seen as the problem and timber as the proposed solution. Although these materials indeed play a major role in the carbon footprint of buildings, they are not the only materials and considerations that should be talked about. This awareness seems to be there, but the way to express other areas of attention or a common vocabulary seems to be lacking.

“We are providing the whole palette of options at the beginning. We could also immediately say: concrete is not going to be it. No, it also has its advantages. So we always put all the variants on the table, with index numbers” Structural engineer

Discussing carbon is not considered one of the most engaging and enjoyable topics, as it is a complex issue. Therefore, tools which are used during the design team meetings and in communication are crucial according to the structural engineer. In the Jaarbeursplein project, the use of images and graphics has helped a lot in the consideration of different structural methods and materials. Even when these images and graphs are a rule of thumb or based on previous buildings. It seems to be that the amount of embodied carbon does not trigger nor activate the design team members, as the understanding of what is number means is lacking. This understanding can be created, by using the carbon impact amounts with the conventional unit (kgCO2e/m2) in conversations.

“When you start talking about MPG, not everyone is always awake. At the moment, when you talk about what it looks like in terms of images, visuals, and graphics, in which you show the different carbon impacts of the structural elements, you get people’s attention” Structural Engineer

Input for the prototype
• **In conversations about often only concrete, steel, and timber are mentioned, neglecting other building materials. There is a need to create a common language in which carbon is discussed** • **Tools such as images and graphs can increase the uptake of information and create a common understanding.** • **Using the actual carbon impact amounts in communication, rather than the rule of thumb will increase the carbon vocabulary of the design team.**

4.3.7 The standards

Tension: Uncertainty regarding standards and regulation

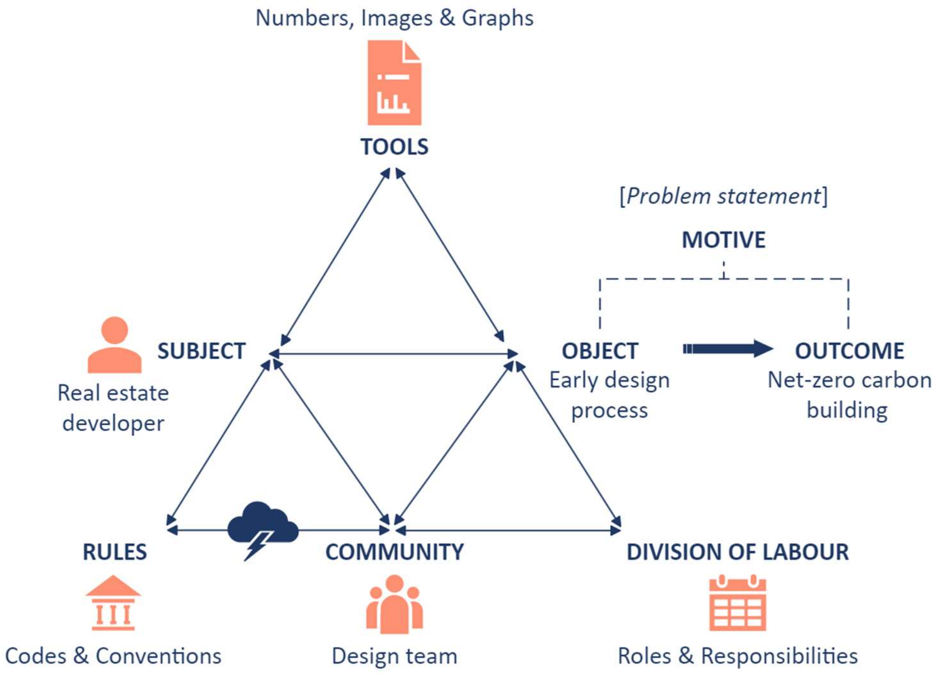


Figure 4.9: Identified tensions and contradictions visualized in activity theory framework (own ill.)

Including embodied carbon is a new activity for both the real estate developer and the design team. According to the developer and building physics consultant, a lot is still unknown and like in the early adaption of accounting for operational carbon, the current standard, and regulation are incomplete and lagging. There is a lot of uncertainty surrounding the subject. For example, the consultant pointed out that everything that is extra-legal does not have to be included in the MPG. While for BREEAM and other sustainability labels, extra-legal measures are required to get to a specific level. These currently do not have to be accounted for in the MPG. However, in the Jaarbeursplein project, they choose to do this anyway, because the real estate developer felt like this should be included.

"The use of solar panels is interesting, currently everything that is extralegal does not have to be included in the MPG. So there can be a huge gap between the number of solar panels that are taken into account in the MPG and what you are going to put on your roof or façade. Solar panels simply score very poorly when it comes to carbon" Cost consultant

Another interesting and debatable subject is the inclusion of biogenic carbon sequestration in the assessment and final calculated footprint of the building. The building physics and sustainability consultants both brought forward that there are different views on how to cope with the carbon sink potential of timber and other bio-based products. When this is included in the assessment it can have a huge impact and even make the building "embodied carbon positive". In the Jaarbeursplein project, this would bring the score of 240 kgCO2e/m2 GFA down to only 79 kgCO2e/m2 GFA.

"How you treat carbon sequestration doesn't matter that much in the MPG, because if you include carbon sinks in the production and construction phase it is released at the end, and with some products, it is simply not included, so below the line it is similar. While if you look at Paris Proof, you are not allowed to include carbon sequestration" Building physics consultant

When inquiring about how the MPG is currently controlled, the cost consultant provided an answer that represent the view of multiple interviewees. The national requirement for the MPG of 0.8 for office buildings is considered quite easy to achieve. As a result, interviewees admitted that they were not sure if there was strict control on the actual input for the MPG. This represents a wider feeling among the interviewees on how current standards and regulations are checked.

"It would be good if there would be some extra check, because of course you have to draw up and submit an MPG calculation for your environmental permit, but how they look at it is very minimal. First of all, the requirement of 0.8 is not a challenge. I think they just go through the documents and see a score of 0.8 or below and think, it's fine" Cost consultant

Input for the prototype
• **The uncertainty surrounding current standards and regulation makes including embodied carbon a harder activity to start with.** • **The inclusion of carbon sequestration can have a vast difference in the embodied carbon footprint of the building.** • **There should be a check on whether extra-legal measures are included in the carbon assessment.**

4.3.8 Summary of Tensions and Contradictions

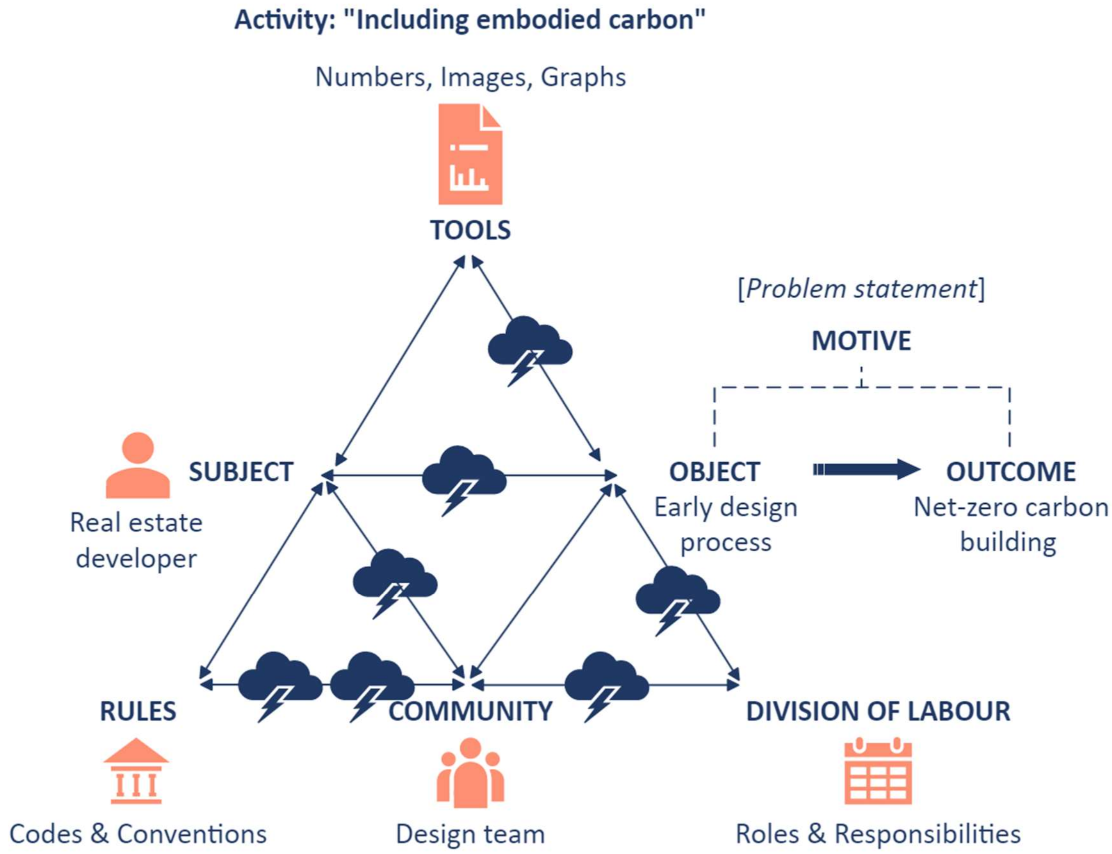


Figure 2: Overview of identified tensions and contradictions

The identified tensions and contradictions in the activity theory framework suggest that there are several areas for improvement in the status quo way of including embodied carbon. The majority of the identified tensions and contradictions are concerned with uncertainty about targets, standards, and roles. This is not surprising, given that including embodied carbon during the early design process is a relatively new activity, and there is still much to be learned from best practices and effective approaches. However, to improve the process and increase the uptake of reduction approaches, these uncertainties should be resolved. For example, clearer targets and standards could be established, and roles and responsibilities could be more clearly defined.

Another significant finding is that often in the conversations regarding embodied carbon, only timber, steel, and concrete are mentioned. This implies that the level of knowledge concerning the embodied carbon impact of other building materials is low. To address this knowledge gap, education should be prioritized so that real estate developers and design team members can make informed decisions about the materials they use. In addition, increased collaboration and communication between suppliers and the design team members can help.

Chapter 5

Findings: Phase 2 (Prototype)

/05 Findings: Phase 2 (Prototype)

In the second phase of the findings, a prototype is developed and presented. The ultimate goal of this research is to guide real estate developers. The prototype serves as an initial model of this guidance, which is later refined and validated through a focus group. Before developing the prototype, first, its requirements need to be clear.

5.1 Requirements for the prototype

5.1.1 Description of the real estate developer interviews

Explorative interviews with real estate developers were conducted to understand their role within the early design process and set requirements for the prototype. Furthermore, the interviews allowed inquiring about net-zero carbon and their knowledge and understanding of embodied carbon. Knowing the level of knowledge helps with determining to what extent things need to be explained within the prototype. Although no questionnaire was used, the interviewees did got send the following list of topics before the interview:

- *The role of the developer and design team members during the early design process.*
- *Products produced during the early design process.*
- *Making design decisions.*
- *Knowledge of "embodied carbon" and "net-zero carbon buildings".*
- *Using manuals, frameworks, and tools during the early design process.*

5.1.2 Results of the real estate developer interviews

According to all interviewees, the goal of the real estate developer during the early design process is to be the overarching guardian of the project, by integrating different disciplines and specializations to accommodate a holistic design. There were, however, different interpretations of what is considered as "early", one interviewee clearly stated that anything until concept design (Structuur ontwerp) can be considered early, while others saw early as up to and including spatial coordination (Voorontwerp). The phase before the concept design was seen as one phase, often referred to as the "Mass-study" or "Acquisition phase". While they mention the safeguarding of all disciplines, there was one discipline; the (building) cost, that was mentioned more than others.

The topic of embodied carbon came to the front quite early in the interviews and was considered one of the disciplines that needed to be managed. On the question of whether the developer should be responsible for embodied carbon accounting and assessment themselves, there was a clear response:

“I would never do that (conduct the embodied carbon assessment), because then you attract way too much work. You should always leave the specializations with the specialist.” Developer B

As performing and updating embodied carbon assessment is currently not a responsibility of an existing role during the early design process, there is a question of which role should be responsible or whether a new role should be created. Different specialists were mentioned to take on this role; the building physicist, the cost specialist, and the sustainability advisor were mentioned the most.

The interviewees saw themselves as the main decision-makers when it comes to design. The design team presents several options or scenarios, and design decisions are made based on them in the (bi)-weekly design team meetings. When discussing decisions on materialisation, one interviewee proposed:

“What is interesting, if you want to focus more actively on materialisation, is to involve market parties such as suppliers or subcontractors at an early stage .” Developer A

The involvement of suppliers and subcontractors at an early stage is proposed to bring more detailed information earlier in the process. Although, the timing of involving these suppliers and subcontractors should be considered carefully and is not favourable already in the Mass-study phase as this is way too early according to the interviewee. The level of detail of the design products within the early design process can differ according to the interviewee, some projects require more detail earlier.

When discussing the financial consequence of accounting for embodied carbon, it became clear that it is still unsure of what the costs would be. However, the interviewees were also not concerned about the amount, as they expected that this will pay out in the future. One interviewee was aware of the offsetting costs and stated that:

“To get an acquisition done, a lot has to happen and then the carbon is currently the most uninteresting, financially speaking, to do the deal […] 1 percent is carbon, not even, half a percent. If we make a mistake with that or it is not entirely accurate, it does not hurt that much. We have also included unforeseen costs.” Developer C

This interviewee referred to the costs of offsetting the remaining carbon and the budget that needs to be reserved for this in the feasibility analyses, which is currently a really small amount (0,5 to 1,0 percent of the total budget). When asked about the so-called 'tipping point,' or the point at which carbon offsetting costs become sensible in feasibility analyses, the interviewee responded that it will be bothersome if the offsetting costs reach three or four times as much. Then it becomes almost as high as the fee for the architect or advisors. Another interviewee saw it more as a cost-benefit, that what you can save in your design, you do not have to offset. Yet another interviewee argued that it could well be possible that investors are willing to pay more for a net-zero carbon building, which could cover the offsetting costs.

5.1.2 The requirements

Inquiring about what the real estate developers would need from the prototype to help them steer on including embodied carbon, provided several requirements both feasible and unfeasible.

Feasible requirements

First of all, the prototype should explain the process and the deployment of the design team member (actors) that needs to be involved. The second requirement was that it should exist of several parts and thereby create a level of detail. In addition, the prototype should not be a step-by-step description of want they needed to do, but rather give guidance and leave options open. Furthermore, it should provide options to reduce embodied carbon and explain what these options can do in terms of impact. Finally, the prototype should be user-friendly and light, as a large document is not desirable.

"I would think that to be able to steer, it would require a kind of process chart on how to deploy your consultants and what topics and options you should consider" Developer B

Unfeasible requirements

Next to the feasible requirements, there were also requirements mentioned that would be good to have in a later stadium, but are out of the scope of this research. First of all, the developers talked about a "tool" that they could use that provides you with all the options and carbon impact of design decisions. They were referring to a design tool that can help them with making fast and calculated design decisions. The interviewees did question whether such a tool would already be feasible during the early design process.

"I think it would help a lot if there was some kind of tool. You have a kind of menu with the impact per material so that you can direct your choices accordingly at an early stage." Developer A

5.2 The prototype

5.21 Introduction to the Prototype

The purpose of the prototype is to visualize the findings of this research and thereby make it insightful. It is a visual representation that aims to increase the transmission of knowledge by linking theory and practice. Within the prototype, interventions are made to solve the tensions and contradictions that were identified within the current practice of including embodied carbon during the early design process of the Jaarbeurs plein project. Although the prototype is a first version, this does not mean that during the development only one version was made. Throughout the research process, the prototype has gone through multiple iterations and taken on a variety of forms, which is explained in section 5.3.

5.2.2 Description of the Prototype

The prototype exists of three parts. In part one, the guidelines that are drawn up based on tensions and contradictions that were identified within the current practice of including embodied carbon are presented. The second part forms the central element of the prototype and includes the process map. The third part provides extra information about the activities that are displayed within the process.

Part 1: The guidelines

The activity of including embodied carbon during the early design process can be challenging to navigate. In order to help real estate developers better understand and address these challenges a set of guidelines has been developed based on the tensions and contradictions identified during the Jaarbeursplein project. These guidelines are not steps, but rather endorsements that could be followed during the early design process. Before delving into the guidelines themselves, the introduction first explains “the why” and the “the what” behind them. “The why” refers to the motivation and purpose behind the guidelines, while “the what” refers to their content and specific recommendations. The theoretical assumption that the impact on the embodied carbon reduction approaches is higher in the early design process and that more than 85 percent of the embodied carbon footprint is distributed among the structure, skin, and services is visualised at the beginning. This is the paradigm through which the guideline and the process map should be viewed.

Part 2: The process map

The process map (figure 5.2) is the central element of the prototype, it provides an overview of the phases, guidelines, and activities. The early design process consists of three phases; the Mass-study (strategic definition + preparation), the Sketch design (concept design), and the Preliminary design (spatial coordination). These phases form the horizontal axis of the map and on the vertical axis, the guidelines are displayed.

The process map presents when the activities should be done and which actor should be involved. As can be seen in the legend, these actors exist of the design team members (Structural engineer, cost consultant, architect, building physics consultant, and MEP consultant) and the external team members (Suppliers and urban miners). A large part of the activities is directly connected to the LCA, represented by the diamond-shaped symbol. The multiple LCAs play a fundamental role within the process map, as they act as a point where the carbon is assessed and compared to the target. When the assessed embodied carbon footprint is higher than the target, a reduction should before the process can move on. This creates a feedback loop that helps safeguard the targets. Of course, it needs to be emphasized that the process map is a simplified depiction of the "design" reality, in actuality this process is more complicated and iterative.

Part 3: The activities

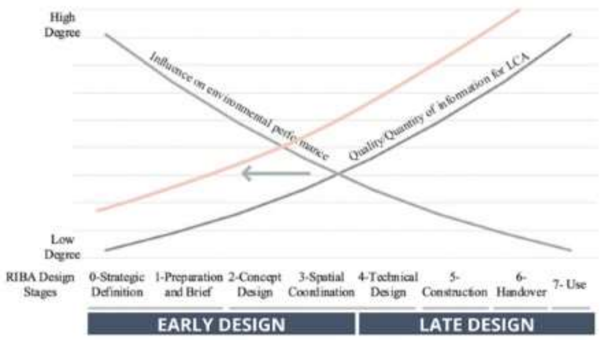
Within the process map, activities are indicated with blue rectangles and a diamond-shaped symbol. These symbols are used to indicate the various tasks and decisions that must be made in order to complete the process. By clicking on these symbols, users can access additional information that is required to undertake the activity. This information is provided in the form of text, tables, and images, which are connected to relevant theory and best practices.

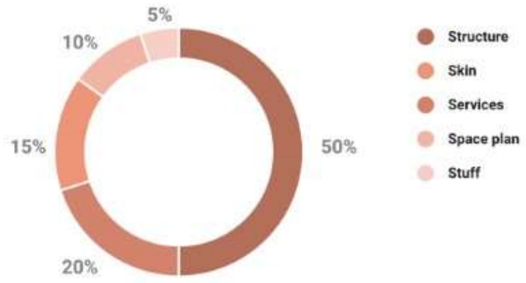
As shown in Figure 5.3, one of the activities included in the process map is 'set embodied carbon target'. This activity involves establishing a target for the embodied carbon impact of the building being developed. However, as this is a prototype, not all the activities are elaborated on. Only the activities of 'reduce impact structure' and 'LCA1' are created and can be found in Appendix X.

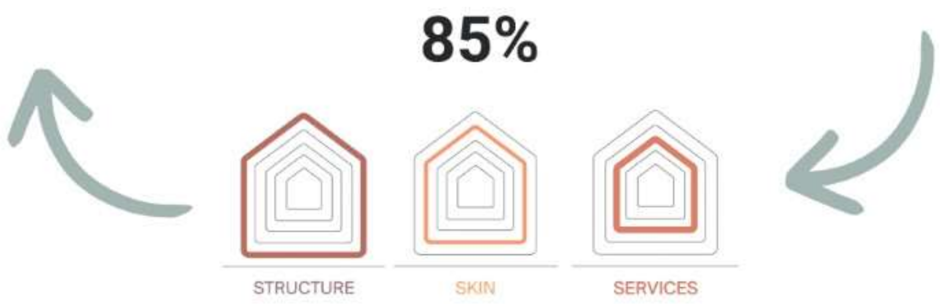
The inclusion of additional information on the activities is crucial to ensure that users have the knowledge and resources necessary to complete each activity effectively. By providing relevant theories and best practices, these activities help to guide real estate developers through the early design process and ensure that they are equipped with the information needed to make informed decisions. Ultimately this will lead to buildings with a reduced carbon footprint.

The journey towards net-zero carbon buildings

Including embodied carbon during the early design process







THE WHY

In achieving net-zero carbon building targets, while operational carbon reduction approaches are striving considerably, approaches to reduce the embodied carbon impact are falling behind. Recent studies show the growing relative and absolute contribution of embodied carbon in buildings. Although having methods such as life cycle assessment (LCA) to asses embodied carbon during the early design process. In current practice, LCA is typically used late in the design process, when it is too late to significantly affect the design. The main barriers are the availability and accessibility of detailed data and the appropriateness of tools, methods, and guidelines for early-design process use. We know where to focus on, as the vast majority of the upfront embodied carbon (85%) is typically located in the structure, skin and services. However, it is unclear for real estate developers how to steer on including embodied carbon during the early design process.

THE WHAT

This prototype aims to provide guidance to real estate developers by presenting the findings of the research on 'how to steer on including embodied carbon'. Making it an insightful tool that can be used.

It is a visual representation that aims to increase the transmission of knowledge by linking theory and practice. Within the prototype interventions are made to solve the tensions and contradictions that were identified within current practice of including embodied carbon during the early design process.

The prototype includes guidelines and a process map. These guidelines are not steps, which should be followed, but rather endorsement to keep in mind during the early design process.

How do I steer on including embodied carbon?

GUIDELINES

1. Use a **target** approach

Set a target for the whole building based on national targets both for upfront embodied carbon and life cycle embodied carbon. Use a stricter target for re-development projects. Derive a separate upfront embodied carbon target for the following building layers; Structure (50% of target), Skin (15% of target) and Service (20% of target).

2. Appoint a **carbon assessor**

The responsibility of carbon assessment should be handled by one design team member. The cost consultant is in a good position to act as the carbon assessor, as they are already collecting quantities and materials for the cost estimate. Decisions can be based on both carbon impact and cost impact. The carbon assessor should proactively request information from other design team members.

3. Reduce **upfront**, Re-think **lifecycle**

Aim for the reduction of upfront embodied carbon. Focus on the structure, skin and services. Request the carbon footprint from product or materials, when they are proposed by the architect. Use design for deconstruction principles and document the materials through for example a material passport and communicate this with the prospected building owner.

4. Conduct **multiple assessments**

The carbon assessment should be done gradually during the early design process, in order to steer on estimates rather than educated guesses.Carbon assessment should be handled as precise as cost assessment, adding contingency in the form of a surplus (10%) on top off the assessed carbon footprint to account for uncertainty.

5. Involve **suppliers** and **urban miners**

Partner with suppliers and urban miners for building components with a high carbon footprint (e.g. floor, window, climate installation). Benchmark the products of the suppliers with other market parties. Create an 'Environmental Product declaration' together with supplier to enter into the 'Nationale Milieu Database'.

6. Create a **common language**

When discussing carbon, try to stay away from only talking about timber, concrete and steel. Get a feeling for the carbon footprints of regularly used building materials, such as glass or stone. Communicate the target and the assessed carbon footprints, using the same unit in conversations (KgCO2e/m2).

7. Challenge existing **standards**

Including embodied carbon is a quite new activity for real estate developers, but also for the building and construction industry itself. Existing standards and regulations are incomplete and lagging. Instead of using these shortcomings to lower the embodied carbon score on the short term, these standards and regulations should be challenged in order to improve them.

Figure 5.1: Prototype part 1 (own ill.)

The journey of including embodied carbon

This process map shows the guidelines on how to steer on including embodied carbon during the early design process. The early design process includes three main phases (MASS-STUDY, SKETCH-DESIGN and PRELIMINARY DESIGN) in which activities take place.

When clicking on the activities within the process map, more information about that activity will appear. As this is a prototype version, only three activities are clickable at the moment: Set embodied carbon target, Reduce impact structure and LCA 1.

Legenda

Design team

- Structural engineer
- Cost consultant
- Architect
- Building physics consultant
- MEP consultant

External team

- Supplier
- Urban miner

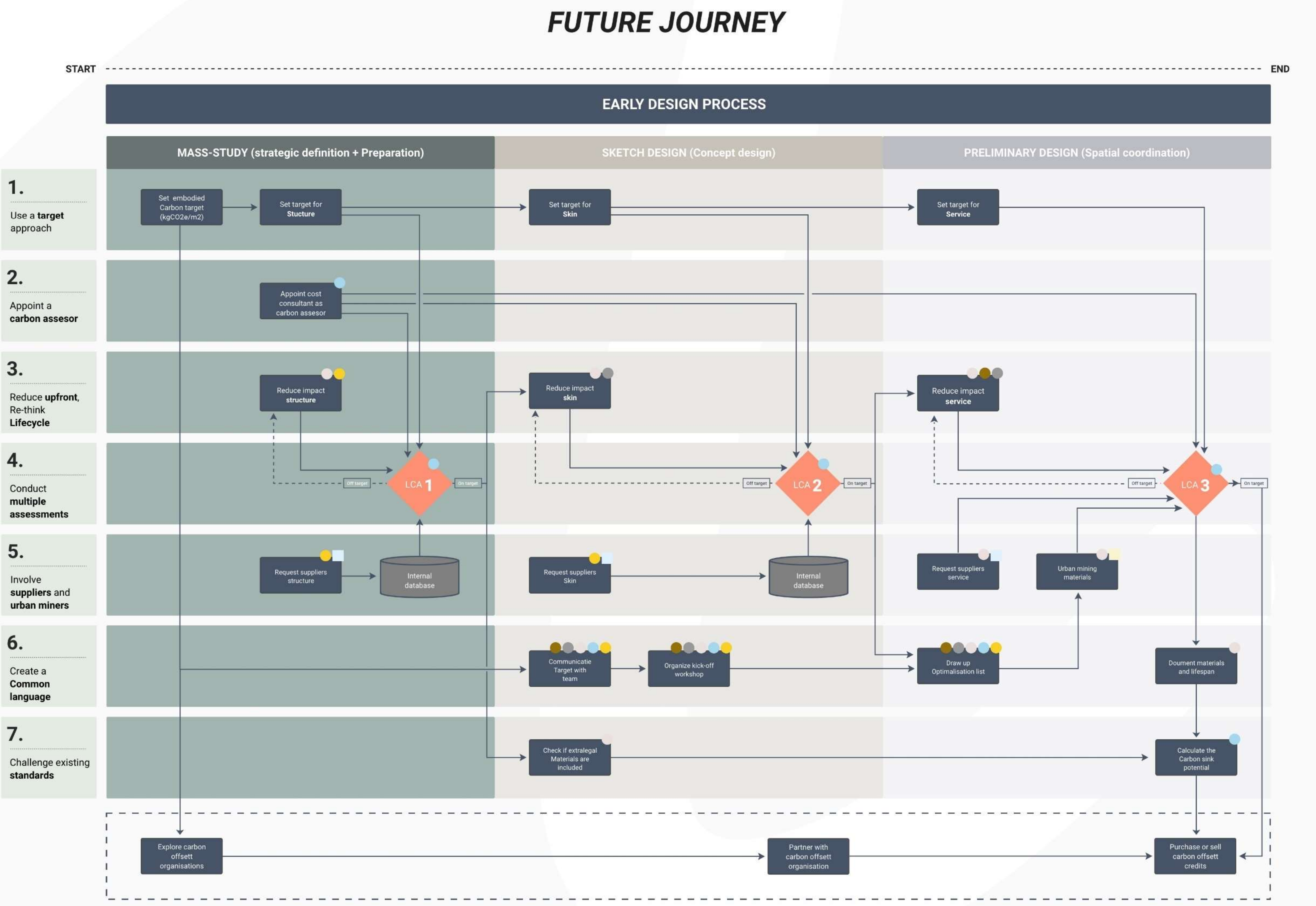
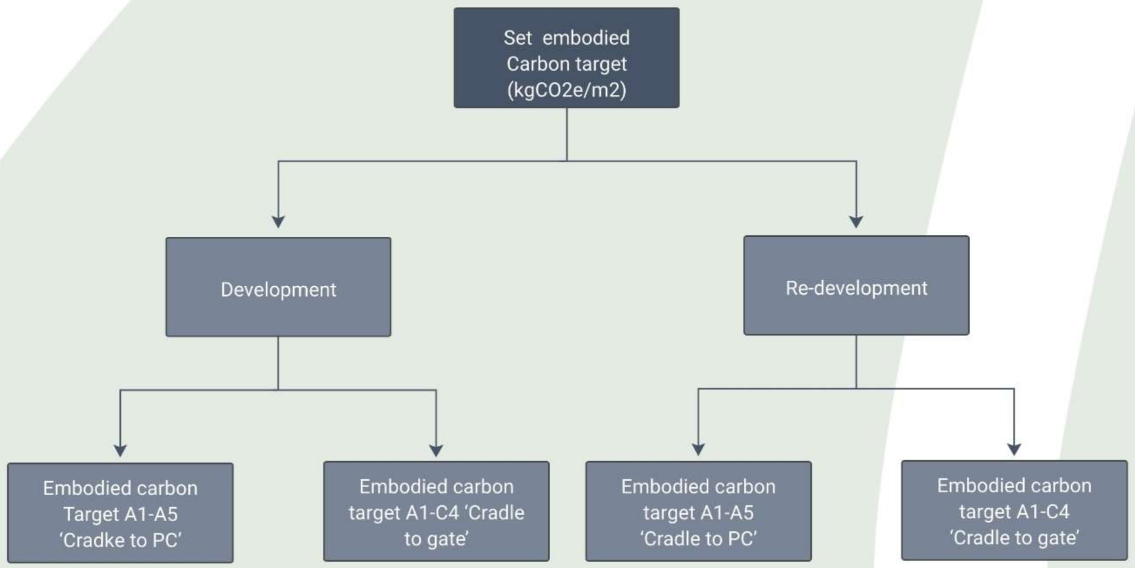


Figure 5.2: Prototype part 2 (own ill.)

Set embodied carbon target

Setting the right target is crucial when steering on the reduction of embodied carbon.

There is no unified consensus on the business-as-usual embodied carbon average which could be used as a baseline for setting an embodied carbon target. For that reason, targets vary both on a global and national level. Target setting is important when steering on the reduction of embodied carbon. The Dutch Green Building Council (DGBC), proposed the 'Paris Proof' limit values. The values differ for development and redevelopment project. Furthermore, these values are decreasing over the years. The advice is to use the target value for the year in which the practical completion will take place.



Paris Proof Target (*Development*)

Paris Proof embodied carbon targets new development (DGBC, 2021)

Paris Proof limit values	embodied carbon kg CO_2-eq. per m²			
	2021	2030	2040	2050
Residence (single-family home)	200	126	75	45
Residence (multi-family home)	220	139	83	50
Office	250	158	94	56
Retail real estate	260	164	98	59
Industry[5]	240	151	91	54

Paris Proof Target (*Re-development*)

Paris Proof embodied carbon targets re-development (DGBC,2021)

Paris Proof limit values	embodied carbon kg CO_2-eq. per m²			
	2021	2030	2040	2050
Residence (single-family home)	100	63	38	23
Residence (multi-family home)	100	63	38	23
Office	125	79	47	28
Retail real estate	125	79	47	28
Industry	100	63	38	23

Figure 5.3: Prototype part 3, set embodied carbon targets (own ill.)

5.3 The process of creating the prototype

The creation of the prototype happened alongside doing the research. Following the research through design principles, the designing act of creating a prototype is in itself a potential generator of knowledge. The design process is characterized by trial and error, without trying there is no progress. Making small sketches when doing research helped to differentiate between important findings and less important findings. These sketches can be viewed as the first versions of the prototype. Later on, during the creation of the prototype, a lot of tools were used. Switching between tools helped to view the process in different ways. As real estate developers are often working with Excel an attempt was made to also create the prototype in Excel. However, while Excel is great for making calculations, it is less suitable for visualisations. Programs like Visio and Miro, on the other hand, are more suitable for visualising a process map. A more in-depth explanation of the use of Research through design to create the prototype is presented in the Reflection (Chapter 9)

Chapter 6

Findings: Phase 3 (Validation)

/06 Findings: Phase 3 (Validation)

In the third phase of the findings, the prototype is validated and improved through two separate focus group discussions. The first session was an internal validation (at the graduation company), and the second session was an external validation with the previously interviewed design team members. The guidelines had a central role in the discussions.

6.1 Focus group approach

The validation of the findings was done through a focus group. Within a focus group, the emphasis lies on a particular topic, and several people are placed together to discuss this topic (Bryman, 2012). In this research the 'topic' is the prototype and the 'people' are real estate developers. The objective of the focus group was twofold. The first objective was to validate the findings from the interviews with the design team members of the Jaarbeursplein project. The second objective was to improve the prototype, that was created based on the findings in the Jaarbeursplein project and the theoretical background. Furthermore, the usability of the prototype was tested by granting the participants individual access to the prototype.

The internal session consisted of five real estate developers and one sustainability expert. These participants were selected through convenience sampling and both concept developers and senior developers took part in the focus group. The session was held in Dutch, as all of the participants spoke this language. The external session consisted of a part of the design team members (Architect, Cost consultant, Building physics consultant, structural engineer and supplier) of the Jaarbeursplein project, that were interviewed before.

6.2 Content of the internal session

The first session started with a short introduction from the moderator about the research itself and the purpose of the focus group session within this wider research. Thereafter, the prototype was discussed. Before the session, the participants got sent a link to the online version of the prototype. To engage the participants in the discussion and make them familiar with the prototype, first, a couple of engagement questions were asked. The general opinion about the prototype and its usability were discussed. To create a discussion on the content, statements were used alongside the prototype. These provocative statements are either confirming or invalidating the findings. Each statement represents one of the guidelines. They acted as the start of the conversation about that specific guideline and that part of the prototype. The participants were asked if they agreed or disagreed with the statement and if they could explain the reason behind their choice.

Table 6.1: Statements (own ill.)

Guideline	Statement
Use a target approach	1. Steering is only possible if separate upfront embodied carbon targets for each layer (Structure, Skin, Service…) of the building.
Appoint a carbon assessor	2. The cost consultant is the most suitable design team member to be appointed as the carbon assessor.
Reduce upfront, Re-think the lifecycle	3. It is only possible to steer on upfront embodied carbon, because a real estate developer doesn't have a say in what happens with the building when it is in-use.
Conduct multiple assessments	4. Carbon assessment can only happen at the end of each phase and can never be as precise as cost estimations.
Involve suppliers and urban miners	5. There is no time to partner with several suppliers during the early design process, and it is also not desirable to already commit to a supplier.
Create a common language	6. Dedicating specific design team meetings or part of a meeting to embodied carbon is way too much attention for this subject.
Challenge existing standards	7. I only do what has to be done according to the regulations or sustainability labels, doing more or challenging them would be a waste of my resources.

6.3 Analyses of the internal session

The prototype appeared to be clear to the participants, although it took some time for them to become acquainted with it. The first comment was made on the mass-study phase. According to one participant, the only focus of this phase is the project feasibility and setting goals, the design is secondary as this will likely be altered many times. Therefore the number of activities in this phase should be limited. The second comment was made on not what was shown, but rather on what was missing in the prototype. This started a discussion about the role of carbon offsetting, which was left out of the prototype as this could be seen as a quick fix. However, both the cost of offsetting and the activities to purchase offset credits need to be included in the process. One participant provided an example of a project where the extra costs to go for a timber structure instead of concrete would increase to 5 million euros, and purchasing carbon offset credits (€50 per 1000 kgCO2e) would only cost 50.000 euros. This example shows that there needs to be another incentive or requirement for an embodied carbon target, a clear definition of what a net-zero carbon building is could help with this according to the participants.

The prototype also started a discussion about the involvement of suppliers and the role they should during the early design process. The overall sentiment was “We don’t need them, they need us”, which indicates that the developers are not eager to already work with specific suppliers in this phase. For the input of the LCA, there were suggestions made to create an internal database, with the often-used products. This was mainly proposed as there is a low amount of trust in the NMD.

The following opinions were given on the statements that were presented alongside the prototype:

Statement 1: Steering is only possible if separate upfront embodied carbon targets for each layer (Structure, Skin, Service…) of the building.

Participants disagreed with this statement. While setting different goals for each layer would be helpful, steering is also possible when there is only one target for the entire building. Because there is already a lot of confusion about the overall target for the building, this issue should be addressed first before delving into distinct targets for each layer. Furthermore, while it is true that a building has multiple layers, the participants emphasized that in practice, these layers are less distinct from one another than theory may suggest.

Statement 2: The cost consultant is the most suitable design team member to be appointed as the carbon assessor.

The participants agreed that the cost consultant would be the most suitable design team member to be responsible for the carbon assessment. They are considered to be a precise party and they already collect the quantities of materials. There were some concerns about how proactive the cost consultant would collect the information needed from other design team members and how engaged the consultant would be in proposing lower or innovative products. One participant argued that developers would be best suitable as they deal with every discipline, however, due to the time it would take to take collect the data and conduct the LCA, this would not be desirable.

Statement 3: It is only possible to steer on upfront embodied carbon because a real estate developer does not have a say in what happens with the building when it is in use.

The overall consensus was that real estate developers cannot be held accountable for what happens once the building is handed over and therefore should only target the upfront embodied carbon. While it would be possible to hand over a document that requires the building owner to keep building components in the building for a certain amount of time, this is not desirable. The deal comes first It is up to the investor if they require it, not the other way around. According to one participant, these conversations about which assumptions are being taken into the LCA and if they can be aligned with the refurbishment and maintenance schedule of the investor are just starting.

Statement 4: Carbon assessment can only happen at the end of each phase and can never be as precise as cost estimations.

The first part of the statement was largely agreed upon, as the end of each phase is a convenient time to assess since the design comes to a temporary stop. The participants disagreed on the second part. While a highly detailed carbon assessment is hard to achieve, it would be possible and certainly at the end of the preliminary design phase. One participant also added that it is a matter of how much energy and time you would like to put into the creation of data for the assessment

Statement 5: There is no time to partner with several suppliers during the early design process, and it is also not desirable to already commit to a supplier.

In terms of time, it would be possible to partner with a handful of suppliers according to most participants. Nevertheless, the question remains if it would be desirable. There was no consensus among the focus group on this statement. Some argued that it would be desirable if the project requires a specific product or if it could help to achieve BREEAM or other credits. Others argued that they want nothing to do with suppliers in this stage of the design because they do not want to commit to a certain party already during the early design process. If done so, there was the advice to treat the suppliers just like any other consultant and partly take them along in the design team.

Statement 6: Dedicating specific design team meetings or part of a meeting to embodied carbon is way too much attention for this subject.

This statement was disagreed quite unanimously, embodied carbon could be put on the list as one of the sustainability goals. Furthermore, it was proposed to let the cost consultant in the lead when discussing this subject. They should put up their hand when design suggestions are made that would not be in line with the embodied carbon targets that are set.

Statement 7: I only do what has to be done according to the regulations, labels, and standards, doing more or challenging them would be a waste of my resources.

On the last statement the participants reacted that, while they would like to challenge the existing standards, it is hard to do because they are not familiar with them. Challenging BREEAM, for example, is a common practice for most of the participants as the credits are clear. Knowing what exactly goes into the MPG, on the other hand, is less clear. Furthermore, the number of projects where they had to deal with the regulation regarding embodied carbon is low, therefore there is a lack of experience and example projects.

6.4 Content of the external session

The content of the session mainly revolved around how the interventions made in the prototype contributed to solving the tensions and contradictions identified during the interviews. The sessions started with a demonstration of the prototype. After the initial comments, the session continued with discussing the guidelines and their underlying tensions or contradictions one by one. To create room for a small debate, the participants were first asked whether they agreed with the tension or contradiction and second of all if the guideline can partly solve this. Furthermore, as the topic of net-zero carbon buildings and embodied carbon is developing at a fast pace, there was room to also make additional comments on whether the tensions and contradictions were already solved by for example clearer standards or new regulations.

6.5 Analyses of the external session

Use a target approach (The real estate developer is uncertain about the target)

Participants in the session acknowledged that the target was a developing aspect and only after the first carbon assessment was made, it became clear what the actual target would be. They emphasized that using a target value would grow in importance over time, and will likely be a standard in the brief. The suggestion was made to handle the target similarly to how BREEAM (Building Research Establishment Environmental Assessment Method) is handled. It was proposed that embodied carbon should be an integral consideration in design meetings. The participants also highlighted the need to translate the target into Key Performance Indicators (KPIs) for effective monitoring and evaluation. This indicates that the participants are searching for a way make including embodied carbon a standard and familiar practice. The participants highlighted the difference between the clarity provided by the BREEAM label, which conveys specific information about credits that can be earned, and the lack of clarity regarding the embodied carbon target. To allow for flexibility, it was proposed that the target should be more ambitious than what needs to be achieved, similar to how extra credits are built into the BREEAM list.

Appoint a carbon assessor (The responsibility of carbon assessment is split between different roles)

The tension that was identified regarding the responsibility for carbon assessment, which was split between different roles was not necessarily seen as a tension by the participants. Although the need for someone to perform the actual calculations was emphasized, ultimately the developer should be held responsible for the accuracy of the assessment. The participants agreed that it was up to the developer to decide which party or parties should share in this responsibility. Furthermore, there were varying interpretations of the role of the carbon assessor. Some regarded them as a party that monitors the embodied carbon throughout the process, others saw them more as an external party that would verify the accuracy of the carbon assessment. There was discussion concerning the suitability of the cost consultant as the responsible party. Doubts were raised about potential conflicts of interest, as well as their degree of knowledge in carbon assessment. With having the responsibility of both the cost and carbon assessment with one party, some participants argued that the essential discussion between the carbon and cost impact of design decisions would be missing.

Reduce upfront, Re-think lifecycle (Steering on upfront or lifecycle embodied carbon)

Despite the extensive discussion, no consensus was reached on what the developer should primarily steer on upfront embodied carbon or consider the lifecycle impact. The participants stressed the need to do both. According to the participants, this guideline is at the core of the entire embodied carbon debate. Some argued that while certain options might require a larger upfront investment, they could yield long-term benefits. In discussing this topic the concept of “Paris Proof” was often mentioned, referring to aligning the ambitions with the Paris Agreement’s carbon reduction goals. Paris proof encompasses the need to reduce the immediate impact to stay within 1.5 degrees pathways. However, the participants added that only steering on upfront embodied carbon could create the tendency to think that “once it is developed it is no longer my problem”.

Conduct multiple assessments (A late carbon assessment)

The participants recognized the importance of gradual assessment throughout the early design process, to ensure effective decision-making and mitigation of embodied carbon. Moreover, it was acknowledged that this aspect is currently missing. In order to create a feeling of how design changes affect embodied carbon, conducting calculations was deemed necessary. The use of Parametric design was mentioned as a potential approach to facilitate the gradual assessment. The accuracy of the embodied carbon footprint value that would come out of the parametric design programs was, however, questioned. Additionally, the improvement of the ‘Nationale Milieu Database’ for accurate carbon assessment was mentioned as a crucial step that first has to be done. The proposal to add a contingency to the assessed embodied carbon footprint value was met with scepticism. Participants believed that developers would always desire the lowest possible score in practice. This suggests that carbon assessment is still a long way off in terms of how we handle costs.

Involve suppliers and urban miners (Certainty about products versus freedom about choice)

The early involvement of suppliers and urban miners was seen as a positive step in creating more detailed information, although only when done right. The concept of urban mining received the most attention. While participants acknowledged that urban mining is being explored to some extent, they highlighted the challenge of availability and the limited success achieved thus far. The participants suggested that suppliers should collaborate with urban miners, rather than developers, to increase the likelihood of successful implementation. It was noted that urban mining often only occurs on a small scale and can be inefficient when applied to larger projects. Considerations such as material availability and storage were mentioned as potential challenges. Nevertheless, the importance of making the market an active part of the solution and creating competition in sustainable material sourcing was emphasized.

Create a common language (The presumed level of knowledge versus the actual level of knowledge)

While acknowledging that there is still much to learn, the participants expressed the belief that their knowledge has already significantly grown throughout the project. They anticipated further growth as they engage in more projects with a net-zero carbon ambition. The participants recognized the significance of ensuring that everyone involved in the project speaks the same language and has a shared understanding of the concepts and goals. They were open to specific sessions or workshops and suggested that organizing a kickstart session at the beginning of each phase could facilitate knowledge sharing. Furthermore, a feedback loop was deemed necessary to facilitate ongoing learning and improvements. It was argued that the responsibility of creating a common language and facilitating knowledge sharing does not necessarily rest solely with the developer. The participants also highlighted that increasing knowledge should not be forced as it is a process of naturally growing.

Challenge existing standards (Uncertainty regarding standards and regulation)

Challenge existing standards involves tackling the tension arising from uncertainty surrounding standards and regulations. Within the standards and regulations, the uncertainty and challenges with the 'Milieu prestatie gebouw'(MPG) and Nationale Milieu Database (NMD) were mentioned the most. According to the participants, there can be a significant deviation between MPG scores and the control of these scores is lacking. The importance to address these issues was highlighted and the developer was seen as the right party to do so, as they are considered to have an overview of the entire process. In response to these challenges, organizations such as the Dutch Green Building Council (DGBC) are actively working to create and share information and improve transparency, according to the participants. The participants suggest that this transparency is also required in validating and sharing MPG scores. It was noted that the participants did not know of a building project in which it was checked whether the products listed in the MPG were actually also used in the building once it was constructed.

Chapter 7

Discussion

/07 Discussion

7.1 Research aim

The primary goal of this research is to provide knowledge and know-how for real estate developers in the form of guidelines required for steering on including embodied carbon during the early design process and thereby achieving net-zero carbon building ambitions. This is done by answering the main research question: ‘How can real estate developers steer on including embodied carbon during the early design process to achieve net-zero carbon building ambitions?’

7.2 Discussion on the theoretical background

Based on the study of literature, recent research shows that a standard definition of a ‘net-zero carbon building’ is still lacking. To achieve net-zero carbon building ambitions, first, there is a need for a clearly defined definition of what a net-zero carbon building is, what the requirements are, and how it can become widely acknowledged. Furthermore, there is no unified consensus on the business-as-usual upfront embodied carbon average value, given the relatively low sample of case studies in research and the great variety of building types. As a result of which, the distribution of upfront embodied carbon over the different building layers cannot unambiguously be defined for a standard building. In addition to the uncertainty surrounding the current values, there is also no consensus on embodied carbon target values. This is enlarged by the lagging regulation on allowable embodied carbon values for new buildings and redevelopments. On the other hand, carbon assessment methods and instruments that can be used during the early design process are becoming increasingly recognized and accurate. Although there is still a lack of data, suppliers of construction products and materials are increasingly publishing data on their products using an ‘Environment Product Declaration’.

7.3 Discussion on key findings

On the basis of the empirical findings, the uncertainty surrounding a net-zero carbon building definition and the embodied carbon target values are also confirmed. The findings indicate that using a target can be an effective steering mechanism during the early design process, especially when separate targets are set for the different building layers. However, due to the inherent uncertainty surrounding embodied carbon values and benchmarks it is challenging to set the right target. These findings align with previous research by Pomponi, Moncaster, & de Wolf (2018) that an accurate understanding of carbon estimates is a crucial starting point in the carbon debate.

When considering who should be responsible for providing the carbon estimates, the findings of this research propose that a conventional actor, the cost consultant, is best suited to be appointed as the carbon assessor. Mainly because they are already collecting data on the quantities and type of materials used in the building for their cost estimate. This contradicts Sturgis' (2017) proposal of introducing a new actor the 'carbon consultant' to handle the carbon assessment. While a new actor might facilitate discussion between the costs and carbon impact, the findings suggest that this role may not require a separate team member. Furthermore, by making one of the more conventional design team members responsible for carbon assessment, there is a potential for increased adoption of accounting for embodied carbon by real estate developers.

However, for which part of the embodied carbon impact over the building life cycle the developer can be held responsible remains unclear. It is debatable that the developer should steer on and reduce the upfront embodied carbon (Life cycle module A1-A5). Not only because the upfront embodied carbon is typically responsible for the majority of embodied carbon across the building life cycle stages (Rasmussen et al., 2018; Röck et al., 2020), but also since the real estate developers' obligations often end after practical completion at the end of stage A5. Nevertheless, rethinking or thinking about life-cycle embodied carbon is similarly important during the early design process. Backing the proposal of Sturgis (2017), life-cycle thinking should be embedded within the design process from the start. The validation sessions also highlighted the importance of not prioritizing upfront embodied carbon over lifecycle embodied carbon during the early design process.

The findings indicate that conducting multiple carbon assessments throughout the early design process is possible and highly desirable, which supports the theory that gradual assessment is necessary to steer on embodied carbon (Häkkinen et al, 2015). Although, the finding suggests that the amount of times the carbon assessment can be utilized is limited to the end of each phase, which comes down to two or three times during early design. This would be an improvement on current practices as typically carbon assessment is done late in the design process when it is too late to significantly affect the design (Roberts et al, 2020). Furthermore, the findings indicate that the assessment should be done in a standard and familiar way, in which the data and information is clear to all design team members.

The early involvement of suppliers can be used as a way to increase the accessibility of detailed information in the search for low-embodied carbon materials, tackling one of the barriers identified by (Roberts et al., 2020). However, involving suppliers requires commitment and decreases the freedom to choose alternative products in a later stadium. Based on the findings, the early involvement of suppliers is possible but should be limited to a low amount. The role that urban mining can play in decreasing the embodied carbon footprint by selecting alternatives for high embodied carbon impact products is promising. The findings suggest that urban mining will have a more prominent role in the design process in the upcoming years, certainly if the embodied carbon target values become stricter.

When discussing the embodied carbon impact of products and materials, the discussion seems to be limited to only debating timber, steel, and concrete. Although it might not be surprising that the general level of knowledge on embodied carbon is low, it is worrying that in achieving net-zero carbon ambitions, embodied carbon knowledge seems to be lagging in comparison to operational carbon. Sturgis (2017) argued that design teams have little or no experience in embodied carbon reduction, which results in them having little knowledge and requiring guidance. However, the findings of Sturgis (2017) have been published six years ago, and the progress that has been made in increasing the level of knowledge seems to be limited.

The empirical findings show that the existing standards and regulations are lagging and that they need to be challenged. Especially on the role that carbon offsetting plays in achieving net-zero carbon building ambitions. The findings implicate that the current carbon offset prices on the voluntary offsetting market do not provide enough incentive for real estate developers to drastically alter conventional practices and the use of traditional building materials. Given the lack of regulation on a required carbon footprint limit value and what type of carbon credits are allowed to offset the remaining embodied carbon, carbon offsetting can be considered a grey area. Existing literature on carbon offsets does also not provide a definite answer to the exact role that carbon offsetting plays in decision-making. The findings of this research suggest that when a price between 200 to 300 euros to offset 1000kg of CO_2e is used as an offsetting price, it could start affecting decision-making. When carbon offsetting becomes a standard in the real estate market, it could as well be possible for real estate developers to also sell carbon credits if their projects embodied carbon footprint is lower than the required target or even negative when considering carbon sequestration.

7.4 Limitations and Reliability

First of all, the theoretical background of this research includes a low amount of academic literature and a relatively high amount of reports and documents from building organisations (e.g. WBCSD and WGBC). Due to the lack of academic literature on especially net-zero carbon buildings and embodied carbon in relationship to early design, these sources were consulted. The impact of this limitation on the findings can be assessed as low since the findings are mainly based on empirical research.

Secondly, the use of only one project in the empirical research part can be considered as a limitation. The credibility of the findings can be questioned, due to the lack of a strong empirical basis. Nonetheless, the amount of (mixed-used) projects that have the ambition to become net-zero carbon is limited, especially in the Netherlands.

Thirdly, the researcher is conducting an internship at a company where they are themselves figuring out how net-zero carbon building ambitions can be achieved, by making decisions on a company level. The observations that the researcher is making, while at the internship company can influence the researcher's bias. Although this is a typical limitation in the research for obtaining a master's degree, it is nevertheless worth mentioning.

Finally, the chosen method for empirical research (Research through design) has its limitations. The creation of the prototype relies on the observations and interpretations of the researcher. There is a possibility that findings are unconsciously altered to fit into the prototype. The impact of this limitation concerning the findings can be regarded as high, mainly because the prototype is made as a way to present and visualise the findings.

Chapter 8

Conclusion & Recommendations

/08 Conclusion

This chapter concludes the research by summarizing the key findings in relation to the research aim and research question(s). In addition, this chapter explains the contribution this research makes to theory and practice. Furthermore, recommendations for further research and practice are proposed.

8.1 Answering the research questions

The main aim of this research is to provide knowledge and know-how and guidance for real estate developers in steering on including embodied carbon during the early design process and thereby achieving net-zero carbon building ambitions. This is done by seeking an answer to the main research question and sub-questions.

8.1.1 The main research question

How can real estate developers steer on including embodied carbon during the early design process to achieve net-zero carbon building ambitions?

The findings indicate that achieving net-zero carbon building ambitions is challenging, especially due to the lack of a standard definition of a "net-zero carbon building", embodied carbon averages, and target values. To navigate through these challenges and bring more detailed information to reduce the embodied carbon footprint in the early design process, this study developed guidelines that can be followed by real estate developers to steer on including embodied carbon.

These guidelines highlight the importance of setting an embodied carbon target for the building. Furthermore, by appointing one of the design team members as the carbon assessor and gradually assessing the embodied carbon footprint throughout the design process, design decisions can be made based on estimates rather than educated guesses. Involving suppliers and urban minders early in the design process can increase the amount the detailed information required for the carbon assessment. However, the number of suppliers and urban miners that are collaborated with should be considered carefully. Dedicating specific design meetings to reducing the embodied carbon impact, can help to increase knowledge and create a common language within the design team. Additionally, existing standards and regulations should be challenged, in order to decrease the uncertainty surrounding them.

The guidelines are visualized and made insightful in a prototype that is created for and through this research. The prototype can act as a learning tool that shows the guidelines over the different phases of the early design process. This is valuable to both theory and practice, as it not only shows what should be done but also how, when, and by whom. This is presented through a process map that displays when the activities required to achieve net-zero carbon ambitions should be performed and which actors should be involved.

The guidelines and prototype are introduced to close the research gap caused by the lack of scientific knowledge regarding the perspective of the real estate developer in the embodied carbon debate. Furthermore, by zooming in on the early design process a step is made to increase the embodied carbon reduction approaches from the outset of the design. Additionally, new knowledge about net-zero carbon buildings is added, enhancing the limited literature available on this topic.

The guidelines can be followed by the frontrunners in building development to rethink their design process and adopt the guidelines in their practice. For the followers, these guidelines can create awareness and start a discussion on the increasing importance of embodied carbon in buildings. The practical application of this research, however, highly depends on the willingness of real estate developers to start accounting for the embodied carbon impact of their building projects.

The research indicates that real estate developers can steer on including embodied carbon during the early design process by using the prototype developed through and for this research, adhering to the seven guidelines, and deploying the actors to the activities that are required. Ultimately this will help them to achieve net-zero carbon building ambitions.

8.1.2 Sub-question one

What are the opportunities and challenges for Dutch real estate developers in achieving net-zero carbon building ambitions by including embodied carbon?

One of the most significant challenges in reaching net-zero carbon building ambitions is the lack of a (global) standard definition of a "net-zero carbon building". This has resulted in inconsistent interpretations and may obstruct widespread adoption. Additionally, there is no unified consensus on the business-as-usual embodied carbon average which could be used as a baseline for setting embodied carbon targets for buildings. The uncertainty surrounding the target values is enlarged by the lagging regulation on allowable values for buildings in the Netherlands. Although embodied carbon emissions are included in the 'Milieu prestatie gebouw' (MPG), which is mandatory when requesting an environmental permit, it does not state the allowable carbon footprint of buildings. Furthermore, extra-legal measures do not have to be included in the MPG.

At the same time, these challenges also provide opportunities. Given that there is not a clear definition and target value, the threshold to start developing net-zero carbon buildings is low. Increasing the uptake of net-zero carbon building development will increase the benchmarks which are needed.

Another opportunity is the increased accuracy of carbon assessment methods and instruments. Suppliers of construction products and materials are increasingly publishing data on their products using an 'Environment Product Declaration", which improves the data that is stored in the data in 'Nationale Milieu database'. Making carbon assessment methods more accurate.

8.1.3 Sub-question two

What are the criteria and assumptions related to embodied carbon that can inform and influence early design process decisions for real estate developers?

The theory suggests that the early design process consists of several phases; Strategic definition (Initiatief Haalbaarheid), Preparation and Brief (Project definitie), Concept design (Structuurontwerp), and the first part of the spatial coordination (Voorontwerp). However, which phases are included depends on the type of project. Important criteria to be able to steer on embodied carbon during the early design process is understanding which building layer is, in general, responsible for which share of the carbon footprint. The exact distribution of upfront embodied carbon cannot unambiguously be defined for a standard building, since the small sample size of case studies and the variety of building types. Nevertheless, it can be assumed that the structure is typically responsible for 50 percent of the total upfront embodied carbon footprint. While services account for 20 percent and the skin makes up 15 percent of the total. Meaning that these three building layers contain the vast majority (85 percent) of the embodied carbon.

One assumption to significantly reduce the embodied carbon in these building layers is to increase the compactness of the building. To specifically reduce the carbon footprint of the Structure, the grid-size should be decreased to a minimum, the use of cement and reinforcing steel should be avoided, and new uncommon (hybrid) structural methods should be explored. A further reduction in the carbon footprint can be made by decreasing the amount of glass used in the Skin. Reducing the number of solar panels can also significantly decrease the carbon footprint of the Services. However, this will affect operational carbon, which applies to more reduction assumptions for the Services layer.

8.1.4 Sub-question three

What are actors and activities during the early design process required to achieve net-zero carbon building ambitions?

All of the conventional actors in the design team are required during the early design process to achieve net-zero carbon building ambitions. However, some actors play a more prominent role than others, and depending on each phase different actors are required. Based on the empirical findings, the cost consultant seems to be best suited to be responsible for conducting the carbon assessments during the early design process, as they are already collecting quantities and materials for their cost estimates. Furthermore, they have insights into both the cost and carbon impact of different design decisions, which can help real estate developers in making considerations. Another important actor that is required during several activities, is the structural engineer. Especially at the beginning of the process when the influence to impact the embodied carbon footprint of the structure is high. When the design is proceeding to the concept design phase, the architect and building physics consultant become more important. Assisting in the activity of determining the open and closed parts of the skin, and the selection of the type of material. Moving toward the end of the early design process, the MEP consultant is needed to reduce the impact of the services. From the carbon assessments, that are conducted by the cost consultant, earlier in the design a list of high-impact service products could help the MEP consultant in choosing low-embodied carbon alternatives.

In addition to the conventional actors, there are also external actors required to achieve net-zero carbon ambitions. Suppliers of construction and building products should be consulted to request detailed information on the embodied carbon impact of their materials. However, the involvement of suppliers requires commitment and should therefore be limited to only partnering with suppliers of the highest impact products, which is project specific. Furthermore, from the high embodied carbon impact list, urban mining materials can be drawn up and requested. In the search for low embodied carbon alternatives, secondary materials can provide a solution.

8.1.5 Sub-question four

How can early design process guidelines be described to steer on including embodied carbon and achieve net-zero carbon building ambitions?

On the basis of the empirical findings, seven early design process guidelines are described that can assist real estate developers in steering on including embodied carbon.

1. *Use a target approach*
2. *Appoint a carbon assessor*
3. *Reduce upfront, Re-think the lifecycle*
4. *Conduct multiple assessments*
5. *Involve suppliers and urban miners*
6. *Create a common language*
7. *Challenge existing standards*

These seven guidelines are not sequential steps, but rather endorsements that real estate developers should keep in mind. Each guideline is equally important and could be followed independently of each other. The seven guidelines are combined with the key findings of this research and developed into a prototype (Appendix A). The prototype visualises these guidelines over the different phases in the early design process. It includes a short introduction on how the criteria and assumptions related to embodied carbon in the early design are interpreted and why the guidelines are required. In addition, a process map presents when the activities required to achieve net-zero carbon ambitions should be utilized and which actors should be involved. Furthermore, it connects the different activities of each guideline to show interdependence. Moreover, additional information necessary to complete the activities can be accessed within the prototype, providing relevant theories and best practices.

8.2 Recommendations for future research

First of all, it is recommended to further test and validate the prototype, which will enhance the internal and external validation. This can be done by using the prototype from the start of new a building project with net-zero carbon ambitions. By testing the prototype in a real project, the logic behind can be validated.

Secondly, a study into the embodied carbon footprint of mixed-used inner city buildings in the Netherlands is highly valuable. Especially when done so in relation to the different building layers and the MPG. This will expose the distribution of embodied carbon in Dutch building projects.

Thirdly, the role that investors play in the decisions making process regarding embodied carbon and the way they value net-zero carbon buildings should be investigated. The effect of net-zero carbon commitments from real estate investors is driving them to also look for buildings that fit their portfolio, which can increase the uptake of net-zero carbon building development.

Fourthly, in order to establish a standard definition of a net-zero carbon building, a study into the requirements for a separate "net-zero carbon building" label or classification can help. This would create more clarity surrounding the definition. Additionally, the research could focus on the relationship between existing sustainable building labels (e.g. BREEAM, LEED) and embodied carbon.

Finally, the role of carbon offsetting in decision-making should be investigated further. According to the findings of this study, carbon offset prices are currently not high enough to be considered an incentive for real estate developers. A study of the tipping point, or the point at which carbon offset costs begin to influence decision-making, could be very valuable.

8.3 Recommendations for practice

8.3.1 Recommendations for the market

As the guidelines and prototype created through this research can already be considered as recommendations for real estate developers during the design process, in this part a wider view is taken and recommendations are drawn up for the market. These recommendations are based on the research, observations, and conversations during the research period. The societal relevance of this research mainly relates to the urgent need to decrease the carbon emissions caused by the building and construction industry. Reaching net-zero carbon at a sectoral level by 2050, ask for a different approach to building development. This not only requires effort from real estate developers but also from other market parties, such as investors, designers, and owners. Although the urgency to develop net-zero carbon buildings is there, the uptake is still very low. Overcoming the challenges for real estate developers that are identified through this research can help, but only once more parties take accountability the vicious circle of blame (figure 8.1) can be broken and net-zero carbon building ambitions can be achieved. Although the original vicious circle of blame might be partly out of date since sustainability is currently a core principle for many market parties, for specifically 'net-zero carbon buildings' it is very much still relevant. Not only because the net-zero carbon challenges what is meant by a sustainable building, it also still needs to establish itself and become a distinctive concept in the built environment.

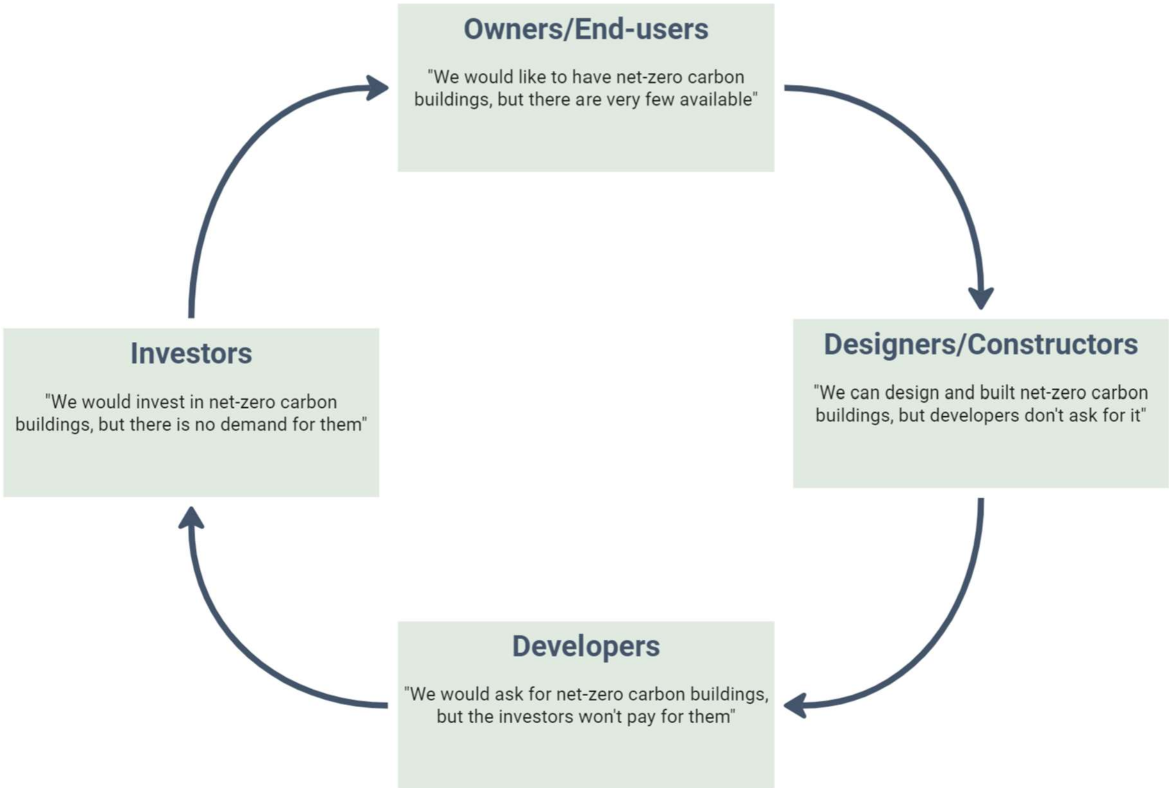


Figure 8.1: Vicious circle of blame (own ill. based on RICS, 2008)

Owners/End-users should not only demand highly energy-efficient buildings (e.g. net-zero energy building), but take it a step further and demand highly embodied carbon-efficient buildings as well. This can be done by first of all preferring re-development over new development. Furthermore, owners should request the use of timber and other bio-based materials, not just for the look and feel of the building but also for the main building components.

Designers/Constructors should start with designing compacter buildings with a smaller grid size. By focusing on the structure of the building, huge steps can be made. Furthermore, they should Increase the use of bio-based and low-embodied carbon materials and products. Additionally, designers should proactively explore and propose new innovative products. Concerning the reduction of embodied carbon, the most notable win-win is reducing the number of materials in the building. This not only leads to a reduced carbon footprint but is also likely to lower costs and less complex construction.

Developers should, next to intrinsic motives, develop net-zero carbon buildings because they have the potential to sell easier and receive a higher price. One of the major steps developers could do to reduce the embodied carbon footprint of their projects is choosing re-developing over developing. Furthermore, they should set an embodied carbon target for their projects and partner with carbon offsetting companies to offset the remaining carbon emissions.

Investors should include net-zero carbon buildings in their portfolio as they fit with Environmental, Social, and Governance (ESG) objectives, which could potentially result in increased portfolio value. However, additional research is required to investigate the extent of this impact. Moreover, it is recommended that investors request developers to provide comprehensive documentation regarding the materials used in the building and their prospected lifespan. This information facilitates an accurate assessment of the residual value of the building.

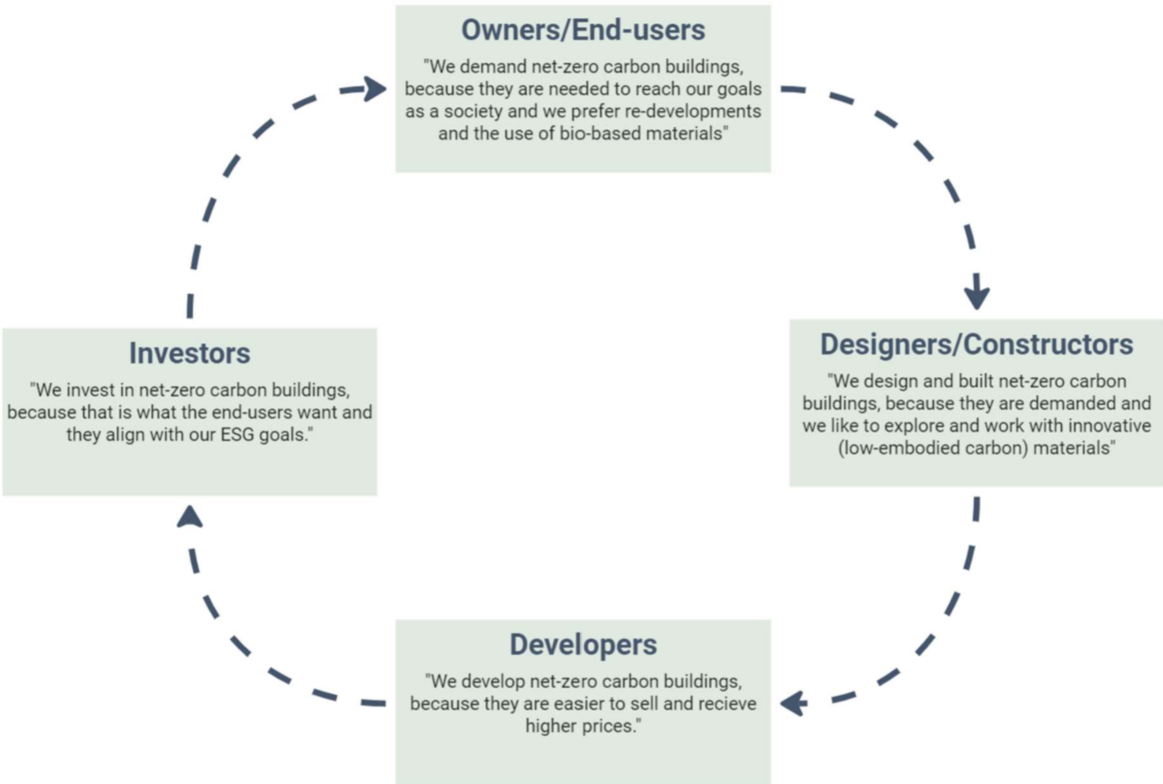


Figure 8.2: Breaking the Vicious circle of blame (own ill. based on RICS, 2008)

Chapter 9

Reflection

/09 Reflection

In this final chapter, a reflection is provided on the research and research process. First, the relation to the wider academic field is reflected. Thereafter, the reflection on the methodology and findings is presented. Finally, a more personal reflection on the graduation laboratory is given.

9.1 Relation to the wider academic field

At first glance, the topic of "embodied carbon" may appear unrelated to the master track Management in the Built Environment (MBE). However, when the topics of "net-zero carbon building," "early design process," and, probably most crucially, the perspective of the real estate developer are added, the relationship becomes much clearer. The relationship between the graduation project topic and the master track MBE mainly relates to the main objective of the research; to guide real estate developers. This guidance is provided during the early design process, which fits perfectly in the research domain of Design and Construction Management.

MBE focuses on solutions for the development and management of buildings and making the built environment more sustainable. While the objective of the research is to guide real estate developers on how to steer on including embodied carbon during the early design process, the overarching goal is to make the built environment more sustainable. This research aids to contribute to reducing the carbon footprint of the construction and building sector. Considerable improvements can be made to the traditional design process by including carbon mitigation approaches from the start. This overarching sustainable goal, is also why the research fits into the broader master program MSc Architecture, Urbanism, and Building Sciences.

9.2 Methodology and Findings

In the P2 report and the graduation plan, ‘case studies’ was proposed as the method for the empirical research. However, towards P3 and during the process of conducting semi-structured interviews with the design team members of one of the case study projects, it became clear to me that case studies might not be best suited as the research method. Mainly since one of the deliverables of the study was to create “something” that could be used by real estate developers. During the week surrounding the P3 the switch was made to use ‘Research through design’ (Rtd) as a research method instead of case studies. This switch of methods was exactly not a switch, but more an organic transition. The decision to go for Rtd did not just come out of the blue, my first mentor had already directed me in this direction a couple of times. However, I was a bit hesitant to adopt this feedback, as almost all of the other students that were working on their thesis in MBE made use of case studies.

Rtd provided the opportunity to further develop the "something", which was named "the prototype", according to the Rtd principles. In addition, Rtd offered the possibility to make sketches and visualise ideas before writing them down. I was already used to making sketches to help me write, as I always have been more of a visual person, which is mainly due to my dyslexia. I was doing Rtd already without really knowing it and using it to organise my thought process. The value of Rtd to my research process is therefore high. Although, Rtd also has a drawback in that you might spend a lot of time designing and are never truly done, especially if you are a perfectionist. Nevertheless, I very much appreciated the freedom this method provided to analyse and order the findings in several different ways.

The findings of the empirical research are particularly valuable for both theory and practice. The academic value of my research mainly relates to the introduction of a new perspective, the one of the real estate developer, to the embodied carbon debate. This perspective was missing, especially in low embodied carbon building design. The societal value of my graduation project depends on how the prototype and guidelines will be interpreted and used by real estate developers. As embodied carbon is a relatively new topic for real estate developers, helping them start by just thinking about it in decision-making can already have a significant effect on society. Especially given the major stake the building and construction industry has in global carbon emissions.

One of the reasons for making the prototype was to visualize and make the findings insightful. To increase the transferability of the research findings, the prototype that is developed should be made publicly accessible. This is, however, not possible given the program in which the prototype is made. What would be possible is to share the prototype in a different format.

To end this part of the reflection, two reflection questions that relate to the content of my work are presented. 1. *What are the strengths of the prototype and how can they contribute to increasing the use of the prototype?* 2. *What were the most important ideas or concepts I learned from the findings?*

9.3 Graduation Laboratory

This year, different themes were introduced within the Graduation Laboratory. Already during the summer, when there was limited information (only one sentence) available about the themes, I decided to focus on and read about the ones that interested me the most. From students of previous years, I had heard that in the first week of the course, you already needed to make a lot of decisions about your topic, mentors, and research question. For that reason, I already prepared myself. However, the first week of the course was way more relaxed than I expected. Choosing a theme was not that difficult for me, the description of theme 5 suited my interest and topic. In the first weeks leading up to the P1, it was unclear what was expected from the theme. We met a couple of times, but not on a regular basis and it was unclear who of the theme “team members” would join the meeting. There were many names of teachers on the list who never joined. For that reason, I decided to use the theme meetings more as a benchmark and consult session than as an integral part of the thesis process. After the P1, the theme meeting became more about knowledge sharing, which was indeed helpful to improve my thesis. What I liked about the theme is that there was a supportive atmosphere, both from students and teachers.

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Appendix A: Prototype

Figure B1: Prototype part 1 (own ill.)

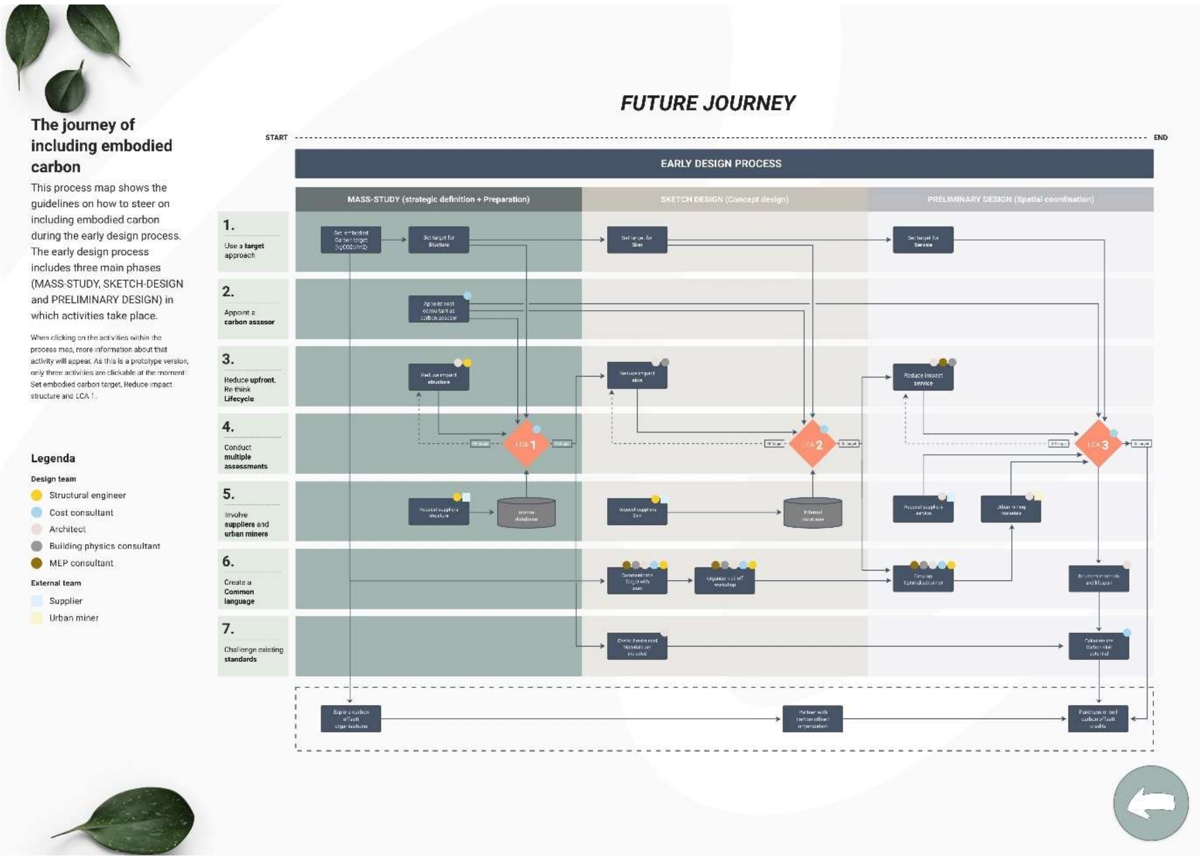

Figure B2: Prototype part 2 (own ill.)

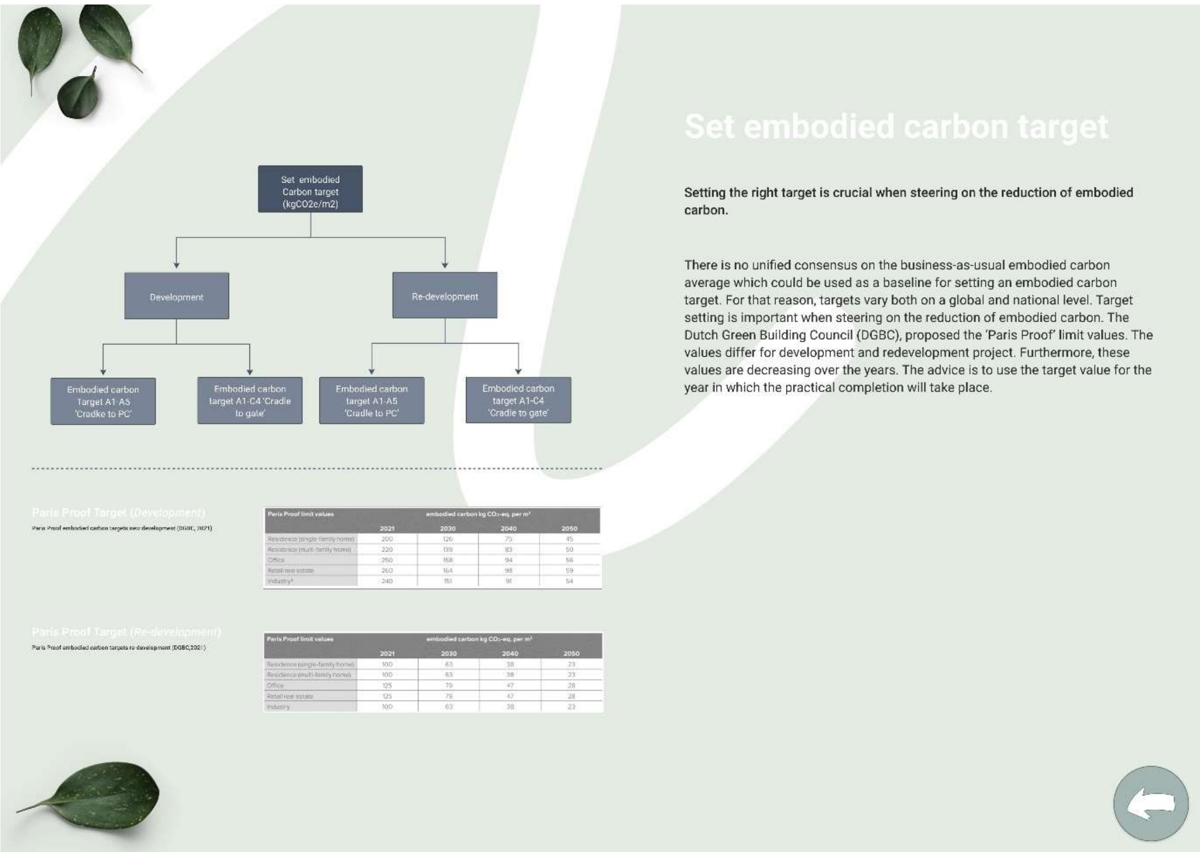

Figure B3: Prototype part 3, set embodied carbon target (own ill.)

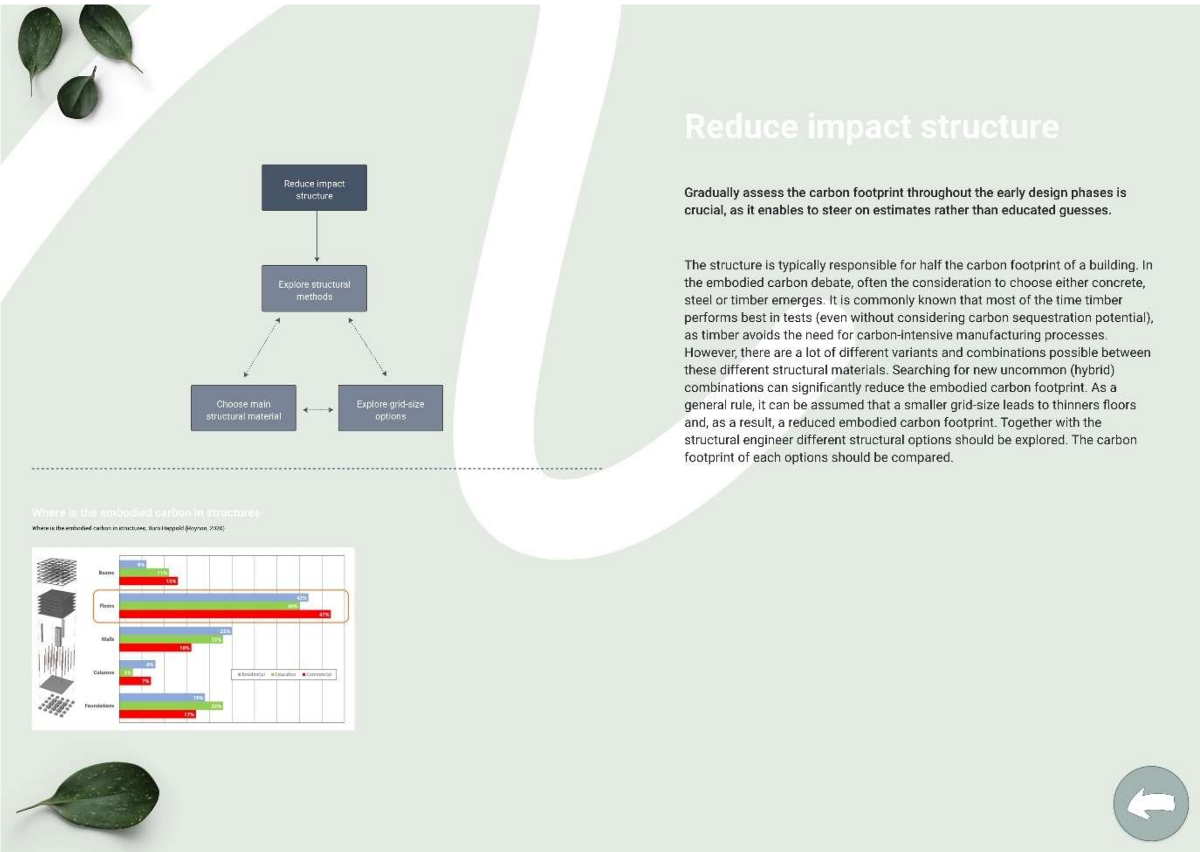

Figure B3: Prototype part 3, reduce impact structure (own ill.)

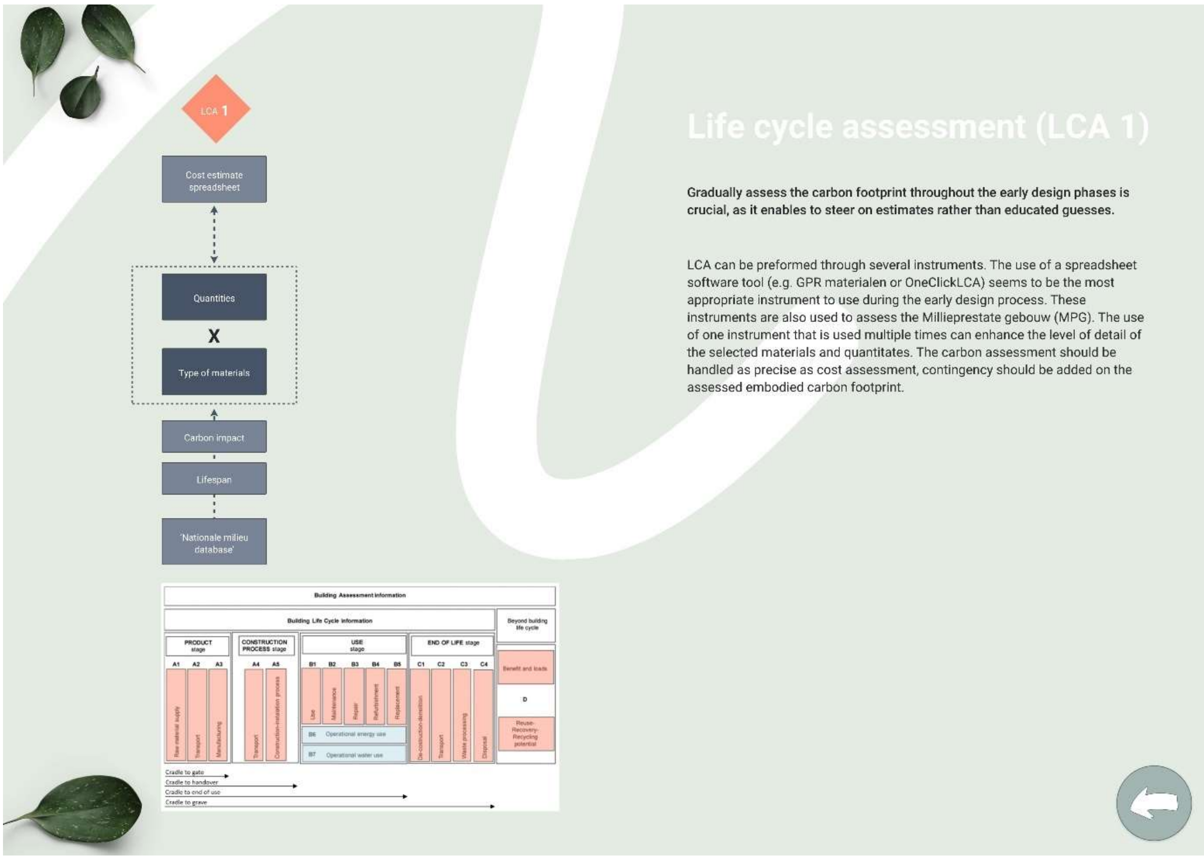

Figure B3: Prototype part 3, Life cycle assessment (LCA1) (own ill.)